"Controlled Hypotension"
in Anesthesia and Surgery

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A Monograph in
The BANNERSTONE DIVISION *of*
AMERICAN LECTURES IN ANESTHESIOLOGY

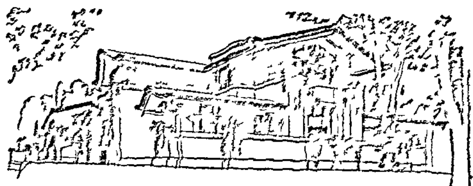
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"Controlled Hypotension" in Anesthesia and Surgery

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To

M S L.

Whose normotension has made
this small monograph possible

CHARLES C THOMAS • PUBLISHER
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"Controlled Hypotension" in Anesthesia and Surgery

I

Introduction

THE CONTROL of gross hemorrhage during surgical intervention, and the rapid, adequate replacement of all blood that is lost, constitute fundamental tenets of sound surgical practice Such control is not always accomplished with facility Hemorrhage is occasionally so profuse as to endanger the life of the patient despite the most heroic remedial measures An even more complex problem is the persistent vascular ooze which often renders operation both tedious and difficult and which may amount to a significant loss of circulating blood volume in the course of a comparatively short period of time Furthermore during certain operative procedures this bleeding need not even be great in quantity to jeopardize surgical success for example, a single drop of blood during the critical stages of the Lempert fenestration operation may obscure the entire operative field and negate a satisfactory result

Within the past few years these problems of excessive bleeding during operation have been the subjects of numerous studies both in this country and abroad, and one solution that has been offered consists of the intentional production of hypotension to achieve a relatively bloodless operative site This concept, while by no means new has recently received widespread notoriety, and is itself sufficiently revolutionary in its character, intriguing in its possibilities, and dangerous in its implications as to warrant detailed consideration

It would be clearly premature at this time to attempt the proper evaluation of these techniques or to estimate

Prudence does not go behind nature and ask whence it is It takes the laws of the world whereby man s being is conditioned as they are, and keeps these laws that it may enjoy their proper good It respects space and time climate want sleep the law of polarity growth and death on the other hand nature punishes any neglect of prudence'

RALPH WALDO EMERSON

II

Bleeding During Surgery

BLEEDING during surgery occurs only when blood vessels, of whatever type or size, are cut Normal blood vessels in the absence of pathological processes involving their walls do not ordinarily permit the gross exit of whole blood from their confines The paramount cause of bleeding during operation therefore is due to the surgical intervention itself Granted however that this is so, there are nevertheless certain other factors of importance in the causation of bleeding which becomes *excessive* during the operative period These have been thoroughly reviewed by Gillies who has classified them into two groups according to whether they are anesthetic or non anesthetic in origin (160)

Non anesthetic Factors In the group of non anesthetic factors (Table I) are those specific pathological conditions which prolong coagulation and bleeding times due to vascular deficiency prothrombin deficiency, platelet deficiency thromboplastin deficiency or fibrinogen deficiency Such dyscrasias if untreated pre operatively are capable of producing varying degrees of abnormal vascular ooze which may become at least troublesome and at times truly dangerous

Other pathological processes particularly those involving the heart or the lungs may also be a source of increased bleeding in the incised tissues when accompanied by venous congestion and an increased venous pressure Diseases that produce a high degree of toxicity with concurrent pyrexia and an increased basal metabolic rate

their ultimate position in anesthetic and surgical practice Too much clinical experience has been amassed over too short a period of time to allow the necessary perspective and too little fundamental investigation into the concurrent, profound physiological alterations has been undertaken to provide the essential knowledge Furthermore the subject is too charged with emotional tension on both sides of the question concerning the absolute propriety of these techniques On the one hand there can be no doubt that induced hypotension for the production of a relatively bloodless operative field when wisely employed in carefully selected cases for a rational indication, may prove markedly beneficial in the individual patient Brunschwig has stated that, hypotensive anesthesia may prove to be one of the most important developments in the refinement of operative technic for complicated surgical procedures that has been made in recent years (68) On the other hand there is accumulating a body of evidence which indicates that drastic reduction of blood pressure in order to decrease bleeding carries a risk greater than that normally borne by the patient during surgery Armstrong Davison a pioneer in the development of the hypotensive technique has revised his original position on the subject and asserts that, the facilitation of the surgical procedure is certainly one of the main duties of the anaesthetist but new measures employed to this end must increase the safety of the patient and not be the means of exposing him to unnecessary hazards (99)

Final evaluation of controlled hypotension —be it acceptance or rejection and probably somewhere between the two—must await a precise knowledge of the hazards involved in its application to the human organism, and a careful deliberation upon those hazards in relation to the advantages that can be obtained by its utilization in the individual patient

large amounts of blood from the tissues and structures in the operative area and thus tend to decrease the degree of vascular ooze and hemorrhage

Anesthetic Factors In the group of anesthetic factors (Table II) that must be considered as influencing the

TABLE II
FACTORS INFLUENCING BLEEDING DURING OPERATION

B *Anesthetic Factors*
  1 *Agents*
    a Effect on bleeding and clotting times
    b Effect of depth of anesthesia
    c Vasodilatation of direct nerve block
  2 *Techniques*
    a Resistance to respiration
    b Increased intrapulmonary pressure
    c Carbon dioxide accumulation

amount of bleeding during surgical procedures, Gillies has directed attention toward both the agents themselves and the techniques by which those agents are administered (160) He has pointed out the fact that although almost all general anesthetic agents have been blamed in the past for excessive bleeding which occurred during operation yet none of those agents in themselves have any great effect upon the bleeding or clotting times of the blood Coagulation time is prolonged very slightly during nitrous oxide anesthesia reduced somewhat during anesthesia produced by ether chloroform and ethylene and unchanged during anesthesia occasioned by cyclopropane or the intravenous barbiturates

On the other hand and of much more importance is the fact that almost all these anesthetic drugs do produce vasodilatation especially of the capillaries of the skin during light planes of general anesthesia This vasodilatation has been attributed to an initial inhibition of the hypothalmic centers causing a reduction of constrictor

lead to excessive vascularity and thus to excessive bleeding during surgical intervention

Profuse bleeding is most apt to occur in the course of certain specific operative procedures both because of the nature of the tissues and structures being operated upon as well as the pathological processes involving those tissues

TABLE I

FACTORS INFLUENCING BLEEDING DURING OPERATION

A Non-anesthetic Factors
1 Deficiencies in the clotting of blood
2 Cardio-pulmonary disease
3 Toxemia Pyrexia
4 Vascularity of tissues
5 Posture

and structures Thus both glandular tissues and large bodies of muscles are highly vascular, and operations involving them may entail significant blood loss certain intracranial interventions (ligation of congenital aneurysm or very vascular tumors) thyroidectomy intrathoracic operations mastectomy laminectomy, operations on the hip or shoulder joints, and some gynecological procedures are examples of the types of surgery during which excessive bleeding may be encountered because of the nature of the operative site itself

Perhaps the most important non anesthetic factor influencing the amount of bleeding during operation however *is the posture of the patient particularly as regards the* site of operation in relationship to the dependent portions of the body If the area of operation is dependent in relation to the rest of the body venous engorgement occurs and there is increased vascular oozing into the surgical field. On the other hand when the patient is so positioned that the field of operation is maintained superior to the rest of the body gravitational venous drainage will remove

As will be noted subsequently, however, the production of an ischemic operative field is scarcely a practicable or justifiable solution to the problem of excessive bleeding during surgery if the price to the patient must be a profound generalized cellular intoxication (90)

Drugs employed as adjuvants to anesthesia for the purpose of facilitating muscular relaxation, such as d tubocurarine decamethonium, or succinylcholine have only weak effects upon ganglionic synapses, except perhaps in truly massive doses As a result both vasodilatation and active circulatory reflexes combine to cause brisk bleeding during anesthesia supplemented with muscle relaxants, unless of course the general anesthesia is carried to very deep levels

Even local anesthetic agents will produce vasodilatation with the single exception that when they are employed for local infiltration and a vasoconstrictor is added to prevent toxic absorption vasoconstriction ensues and a decreased amount of bleeding is encountered When used for direct nerve block, however vasodilatation will occur due to paralysis of the vasoconstrictor fibers of the nerve trunk

At least as important as the anesthetic agents employed, and in certain instances of far more importance, are the methods and techniques by which general anesthesia is administered This is most particularly true of the respiratory factors involved in modern methods of anesthetic administration Increased resistance to respiration, whether due to obstruction of the airway or to increased friction within a closed anesthetic circuit causes an increased venous pressure venous congestion and increased vascular ooze

Similarly the use of assisted or controlled respirations entail the use of increased intrapulmonary pressures which reduce the intrapleural negative pressure or even make the latter positive lift the thoracic wall and force

tone (160), but it is not a sufficient degree of vasodilatation to lower the blood pressure Therefore, since the circulatory reflexes are active in light planes of anesthesia this vasodilatation will lead directly to increased bleeding from the surgical wound

Under such circumstances hemorrhage may be brisk except during anesthesia with those agents which produce a relative hypotension from the very outset, such as chloroform and the barbiturates Chloroform reduces the blood pressure from the beginning of its administration by a combination of vagal and dilator effects and it is this immediate hypotension that is a large factor in decreased blood loss associated with anesthesia by that agent so much appreciated by the surgeons of an earlier generation (51) The barbiturates have a marked depressant action on the hypothalmic centers controlling autonomic activity and thus produce a hypotension albeit a transient one during the induction of anesthesia a bit later in the anesthesia, however the respiratory depressant effects of the barbiturates become more important and offset the decreased tendency toward bleeding attributable to this initial hypotension (128)

A quite different situation pertains during the conduct of *deep* general anesthesia regardless of which agent may be employed to produce anesthesia (42 517) The vasodilatation seen during light planes of anesthesia persists but instead of being associated with those factors which serve to increase blood flow and therefore active bleeding (i e, vasodilatation undiminished blood pressure normal cardiac output and active circulatory reflexes) the vasodilatation during deep anesthesia is accompanied by a depression of the pressor reflexes and a fall in blood pressure Excessive bleeding therefore can be prevented by maintaining deep levels of general anesthesia the amount of bleeding varying inversely with the depth of anesthesia

III

The Control of Bleeding During Surgery

THE PROBLEM of excessive bleeding during surgical interventions is scarcely a new one and for many years both surgeons and anesthetists have applied a variety of different methods in an attempt to achieve hemostasis For the most part these approaches have been of a local nature, confined to the operative site itself or to that restricted portion of the body immediately surrounding the operative area (Table III)

The use of tourniquets and Esmarch bandages for operations upon the extremities has been a well known maneuver for a very long time The application of vasoconstrictor substances to the tissues of the operative site has also been employed to provide hemostasis but the utility of this procedure has been somewhat restricted both by the danger of toxic absorption and by the problem of reactive vasodilatation and therefore reactionary hemorrhage Cautery chemical agents of an escharotic nature, and more recently hemostatic sponges have proven extremely useful in controlling vascular ooze in fairly limited areas of the operative site The local application of both heat and cold have been employed for the achievement of hemostasis in the past, and it seems evident from the recent advances in cardiac surgery that hypothermia will gain prominence for the control of hemorrhage in that type of surgery although as a generalized rather than as a local measure and for a quite different rationale than

the diaphragm downward these maneuvers have the tendency to hinder venous return and cardiac filling rather than to facilitate them as does spontaneous respiration and venous ooze is increased

Finally the failure to excrete adequate amounts of the carbon dioxide produced by the patient is a potent cause of increased bleeding during surgery Uncompensated apnea decreased respiratory exchange due to sub apneic doses of respiratory depressant general anesthetic agents or muscle relaxant drugs or inefficient carbon dioxide absorption for numerous technical reasons in closed system methods of inhalational anesthesia all cause a rise in blood pressure and vasodilatation The importance of the impedance of carbon dioxide excretion as a cause of increased bleeding during surgery has been emphasized recently by the perfection of non rebreathing techniques and the suggestion that they may play a most important role in decreasing vascular ooze during operation (70)

stasis on this basis, of course, is due to the attendant progressive central depression, which leads to hypotension and therefore an ischemic operative field. The gradual realization of the role played by hypotension in producing a bloodless operative site in chloroform, spinal, and deep general anesthesias, has led to the intentional reduction of

TABLE IV

THE HISTORY OF CONTROLLED HYPOTENSION

1946—Gardner—Arteriotomy
1948—Gillies—Total Spinal Block
1950—Davison—Pentamethonium Ganglionic Blockade
1950—Enderby—Hexamethonium Ganglionic Blockade
1951—Guiot and Damoiseau—Pendiomide Ganglionic Blockade
1952—Nicholson Sarnoff and Crehan—Arfonad Ganglionic Blockade

blood pressure and the evolution of so-called controlled hypotension during anesthesia and surgery

While it is true that hypotension has often provided a relatively bloodless operative field in the past it has only been sought deliberately for that purpose during the last few years (Table IV) In 1946 Gardner (149) introduced the technique of arteriotomy whereby blood is withdrawn from the patient pre operatively via the arterial route and then replaced in part or in toto by the same manner at the end of surgery Such pre operative reduction of the total circulating blood volume by the removal of from 500 to 3000 cc of blood serves to lower the arterial pressure to a level between 50 and 90 mm Hg and at the same time produces peripheral vasoconstriction (196) when combined with proper positioning of the patient the net result is a reduction of bleeding at the site of surgery Arteriotomy thus approximates a state of hemorrhagic shock and for this reason has been thought to exceed the bounds of physiological *rectitude*

A more physiological approach to the problem was con

that upon which its earlier use was based Arterial com pression and even temporary ligation, have been used to control hemorrhage in certain instances of vascular sur gery

Without question, however, the most important of these

TABLE III

METHODS OF HEMOSTASIS

A Local Methods	
1	Hemostats ligatures and sutures
2	Tourniquets and Esmarch bandages
3	Vasoconstrictor drugs
4	Cautery escharotic chemical agents and hemostatic sponges
5	Local application of heat or cold
6	Arterial compression or temporary ligation
7	Proper posturing of the patient
B General Methods	
1	Chloroform anesthesia
2	Spinal analgesia
3	Deep general anesthesia

approaches to the problem of hemostasis has been the meticulous positioning of the patient on the operating table so that the operative site would be superior to the rest of the body This maneuver permits gravitational venous drainage away from the operative site into the dependent portions of the body and thus in large meas ure serves to prevent venous ooze

It seems possible, in retrospect that the surgeon s pref erence in the past for chloroform and spinal anesthesia was due as much to the ischemic operative fields which resulted from the hypotension accompanying these forms of anes thesia as it was to the profound muscular relaxation gen erally cited as being the basis for his choice of anesthetic procedure It has also been recognized for some time—and even advocated on a few occasions—that excessive bleed ing during surgical intervention could be prevented by recourse to very deep levels of general anesthesia Hemo-

proaches It might be defined as being a combination of

1 The deliberate induction of hypotension

2 The employment of Dale's postural ischemia

This is in fact, the definition which has come to be accepted in common medical parlance and which will be employed throughout this monograph

tained in Gillies classic studies, in 1948 on *total spinal block* (175) In this method, the blood pressure is reduced to 70 mm Hg, or below, by the use of spinal anesthesia to achieve paralysis of the entire efferent sympathetic out flow, with lesser degrees of sensory and motor blockade so that the muscles of respiration and the medullary centers remain relatively unaffected Gillies has admitted the phys iological deviations of even this technique (161), but he has assumed that the arteriolar dilatation so produced guarantees normal oxygenation of the tissue cells, and that the decreased cardiac output inherent in the technique is compensated for by the decreased peripheral resistance and therefore the decreased work of the heart Proper posturing of the patient is again an essential feature for the control of bleeding as it is indeed in all methods of 'con trolled hypotension'

The introduction in 1948 of easily injectable gangli onic blocking agents in the form of the methonium com pounds (32 362) led to the widespread usage of hexame thonium and pentamethonium to lower the blood pressure to systolic levels of 50 to 60 mm Hg and thus control excessive vascular ooze in the operative field (98 120) More recently, arfonad (344), a thiophanium compound and to a lesser extent, pendiomide, (188) a diethylenetri amine derivative have made possible more readily con trollable forms of ganglionic blockade for the purpose of reducing excessive bleeding during operation again em ployed in conjunction with proper positioning of the patient

A number of other less widely used drugs and tech niques have been applied in similar manner to the prob lem of excessive bleeding during surgery and so-called controlled hypotension is therefore a generic term which includes the total of such diverse clinical ap

less fixed entity under normal physiological conditions can be varied by artificial means as well as by certain pathological processes and therefore may be utilized for the production of controlled hypotension

An intentional decrease of the cardiac output has been sought only by those few workers employing procaine amide (7 311 315 360), a technique of questionable virtue A decreased cardiac output will of course produce hypotension but it is important to realize that the reverse may be true also and to emphasize that *all* techniques of controlled hypotension are usually associated with a quite unintentional reduction of cardiac output This would appear to be unavoidable inasmuch as the cardiac output is mainly dependent upon the venous return the force of the heart beat the rate of the heart and the arterial pressure itself (Table VI) Obviously any reduction of arterial pressure may be expected under most conditions at least to lead to a concomitant decrease of cardiac output (208) Furthermore venous return is also

TABLE V

FACTORS CONTROLLING BLOOD PRESSURE

1 Cardiac output
2 Peripheral resistance
3 Circulating blood volume
4 Viscosity of the blood
5 Elasticity of the arteries

TABLE VI

FACTORS CONTROLLING CARDIAC OUTPUT

1 Venous return
2 Force of the heart beat
3 Rate of the heart
4 Arterial pressure

IV

Induction of Hypotension

THE SEVERAL factors which combine to maintain the normal arterial pressure include the cardiac output the total circulating blood volume the peripheral resistance, the viscosity of the blood and the elasticity of the walls of the large arteries (Table V) These various factors are in turn subject to control and influence by an enormous number of other physiological phenomena of nervous hormonal, and physical origin but for the purposes of this discussion the five basic factors mentioned are of sufficient concern

Of these the latter two—the viscosity of the blood and the elasticity of the large arteries—are fairly constant and not easily altered for the purpose of inducing hypotension It is true that the viscosity of the blood fluctuates markedly during surgery changing with variations in the chemical composition the gas content the temperature the colloids and the suspended corpuscles but these changes are not amenable to deliberate alterations with any degree of control The factors of importance for the reduction of the blood pressure in the techniques of controlled hypotension therefore are the cardiac output, the peripheral resistance and the total circulating blood volume

When the blood volume remains constant arterial pressure is to a great extent the product of the cardiac output and the peripheral resistance and these particularly the latter can be varied by devious maneuvers for the intentional reduction of the arterial pressure The quantity of the total circulating blood volume itself, while a more or

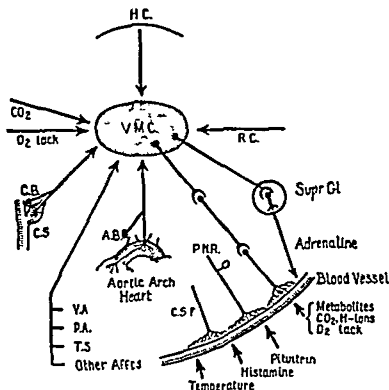


Figure 1 Regulation of Arterial Tone V M C vasomotor centers H C higher centers cerebral cortex hypothalamus R.C irradiation from respiratory center CO_2 central action of CO_2 O_2 lack central action of O_2 lack C B carotid body (chemoreceptors) C.S carotid sinus (pressoreceptors) V.A venae cavae and right auricle (pressoreceptors) P.A pulmonary artery (pressoreceptors) T.S thoracic-splanchnic arteries (pressoreceptors) A B aortic bodies (chemoreceptors) Aortic aortic arch heart (pressoreceptors) C.S F cranial and sacral vasodilator fibres P N R posterior nerve roots vasodilator fibres ———— connector and excitor cells of sympathetic nervous system Supr gl suprarenal gland (Modified from Samson Wright *Applied Physiology* 1943 and reprinted from Heymans C *Introduction to the Regulation of Blood Pressure and Heart Rate* Charles C Thomas Publisher 1950 with the kind permission of the publishers)

reduced in hypotensive states, and becomes a further factor in lowering the cardiac output

Hypotension has been induced intentionally, therefore, mainly by creating a disparity between the quantity of the total circulating blood volume and the capacity of the

TABLE VII

THE PHYSIOLOGICAL BASIS OF THE TECHNIQUES FOR INDUCING HYPOTENSION

1 *Elasticity of the Arteries*—relatively unalterable
2 *Viscosity of the Blood*—not amenable to control
3 *Decreased Cardiac Output*
  A Pronestyl
  B Unavoidable with other techniques
4 *Reduction of Circulating Blood Volume*
  A Arteriotomy
  B Vacuum applied to lower extremities
5 *Decreased Peripheral Resistance*
  A Conduction anesthesia i e Total Spinal Block
  B Ganglionic blockade i e Methonium compounds

(Modified from Little D M Jr Induced hypotension in anesthesia and surgery *Anesthesiology 16* 320 1955 with the kind permission of the publisher)

vascular bed (Table VII) A reduction of the total circulating blood volume is embodied in the technique of arteriotomy or arterial bleeding followed by retransfusion (6) The *effective* total circulating blood volume is reduced by lowering the peripheral resistance by ganglionic blockade, and then applying a vacuum apparatus to the lower extremities almost an eighth of the total blood volume is trapped in the legs and thighs when suction is exerted on the encased limbs (420)

It has been by a reduction in the peripheral resistance however that the arterial pressure has been most easily and therefore most popularly, decreased for the production of controlled hypotension The peripheral resistance resides mainly in the variably contractile arterioles and to a lesser extent, in the capillaries and veins (Figure 1) The

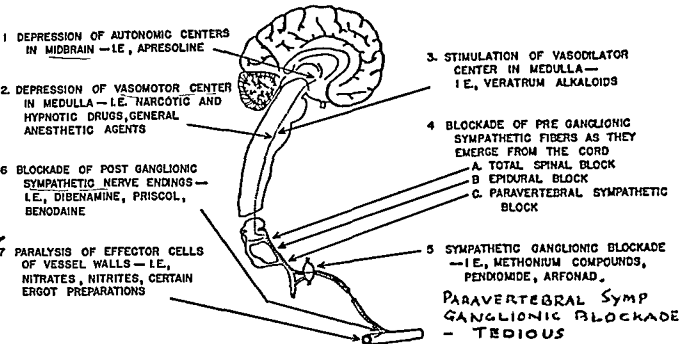


Figure 2 Interruption of sympathetic vasoconstrictor impulses

degree of contraction or tone of the arterioles and probably also of the small veins, is maintained and controlled by several factors, of prime importance among which is the continuous stream of vasoconstrictor impulses that arise within the brain and pass down the spinal cord and out over the sympathetic fibers of the peripheral vessels The peripheral resistance therefore may be reduced by an interruption of this pathway at any point in its course by suppressing the formation of vasoconstrictor impulses, by blocking their pathway to the peripheral vessels, or by preventing the response of the effector cells at the termination of the pathway

Depression of the autonomic centers which are located in the midbrain will result in a decrease in the number and frequency of constrictor impulses arising in those centers and this effect has been employed extensively in medicine for the control of hypertension by the administration of hydralazine (Figure 2) This is a drug however which has not as yet been found practicable for use during surgical anesthesia

Depression of the vasomotor center in the medulla oblongata also will suppress the stream of vasoconstrictor impulses Central vasomotor depression of this type occurs to some degree with most narcotic and hypnotic agents and it is known to occur quite consistently during deep levels of general anesthesia but the deliberate induction of hypotension in this manner has not been considered justifiable because of the generalized cellular intoxication that accompanies such profound central depression

Reflex inhibition of the vasomotor centers (or stimulation of the vasodilator center) will tend to detract from the effect that vasoconstrictor impulses have upon the peripheral vessels and so will cause an increase in the cross sectional area of the vascular bed and a fall of blood pressure This is apparently the mode of action of the

cifically to control the hypertensive crises occurring during the removal of adrenal pheochromocytoma

Finally, the response at the termination of the pathway can be prevented by a direct action of such drugs as the

TABLE VIII

TECHNIQUES EMPLOYED IN 27 930 CASES TO PRODUCE CONTROLLED HYPOTENSION*

Technique	*Great Britain and Ireland Anesthetists*	*Cases*	*U S A Anesthetists*	*Cases*	*Grand Total of Cases*
Arteriotomy	5	206	12	208	414
Total Spinal Block	51	6 922	46	2 655	9,577
Methonium Compounds	*166*	*11,979*	*115*	*3,375*	*15,354*
Arfonad*			16	359	359
Pendiomide*			6	63	63
Miscellaneous	35	2 018	14	145	2 163
Totals	255	21 125	209	6 805	27 930

* *Questionnaires were sent to the 602 members of the Association of* Anaesthetists of Great Britain & Ireland before the general introduction of these compounds into clinical practice

(Reprinted from Little D M Jr Induced hypotension in anesthesia and surgery *Anesthesiology 16* 320 1955 with the kind permission of the publisher)

nitrites the nitrates and certain dehydrogenated ergot preparations, upon the effector cells of the vessel walls themselves Again, however, none of these has proven to be sufficiently controllable to be employed extensively during anesthesia and surgery

This brief discussion of the physiological basis of the techniques for inducing hypotension would be incomplete without some indication of the relative frequency of their clinical application (Table VIII) Questionnaires were sent to the members of the Association of Anaesthetists of Great Britain and Ireland (197) and to the Diplomates of the American Board of Anesthesiology (198), to ascertain

veratrum alkaloids, although these drugs to date have been used little for controlled hypotension

Sympathetic blockade produced by blocking the pre ganglionic sympathetic fibers as they emerge from the spinal cord, by one of the techniques of conduction anes thesia has proven to be a most useful method of inducing hypotension during anesthesia and surgery Total spinal analgesia, which has long been known to produce sympa thetic paralysis in addition to its effects upon motor and sensory nerves has been employed widely for this purpose Similar results achieved by the same metameric distribu tion of sympathetic paralysis, have been obtained by the use of epidural analgesia

Sympathetic blockade also may be effected by blocking the sympathetic ganglia themselves Paravertebral sympa thetic ganglia blockade (which actually blocks the post ganglionic as well as the preganglionic fibers, in some instances) is far too tedious and time-consuming a tech nique for the purposes of controlled hypotension Sym pathetic ganglia blockade however, can be performed with almost indecent ease with the use of such systemi cally acting drugs as tetraethylammonium bromide or diiodide pentamethonium or hexamethonium halides arfonad pendiomide and others These drugs act to block the transmission across synapses within the auto nomic ganglia thereby interrupting the stream of vaso constrictor impulses and inducing hypotension

Constrictor tone also may be interrupted by blocking the sympathetic nerve endings as they terminate in the walls of the blood vessels by the administration of dibena mine priscol regitine or chlorpromazine These drugs are of uncertain and unpredictable action and have found little use in the techniques of controlled hypotension although they have been employed on rare occasions spe

V

Postural Ischemia

PROPER positioning of the patient upon the operating table can often provide remarkable degrees of hemostasis, and had the techniques of "controlled hypotension" contributed nothing else they would have served at least to reemphasize the value of this salutary maneuver to the present generation of surgeons and anesthetists. In controlled hypotension, lowered blood pressure is combined with elevation of the operative site to cause the elevated part to become pale and ischemic—a situation which Sir Henry Dale has described most aptly as "postural ischemia" (127). It is also true, however, that simple elevation of the area of operation above the rest of the body will in itself effectively lessen the amount of bleeding in the wound.

The promotion of venous drainage is of course the most important factor in this regard. If the surgical wound is dependent in relation to all or much of the body, the venous blood in order to leave the wound must oppose the hydrostatic force of the weight of the column of blood in addition to having to exert an anti-gravitational force. Even when the incision is on a level with the other parts of the body, *however, venous drainage may be impeded* by factors which reduce venous return during anesthesia, particularly venodilatation, diminution of the pump action of the negative pressure within the thorax secondary to decreased respiratory excursion, and because of general muscular paralysis a failure of the intermittent pressure which is normally brought to bear upon the venous blood

certain facts concerning the clinical practice of 'controlled hypotension The results of these questionnaires reported some 27 930 cases of 'controlled hypotension in anesthesia and surgery 15,354 or roughly 55%, were conducted by the intravenous injection of the methonium compounds 9,577, or 34% by the induction of total spinal block, which has the advantage of producing surgical anesthesia over much of the body in addition to inducing hypotension 414, or 1 5% by the institution of the somewhat cumbersome technique of arteriotomy 359 and 63, respectively by the injection of arfonad and pendiomide which are relatively new drugs and the remaining 2,163 or approximately 8%, by means of a variety of miscellaneous techniques

almost entirely upon the nature and site of the surgical procedure, except that due consideration must be given to the dangers of ischemia to vital organs in certain postures Craniotomies and other neurosurgical procedures

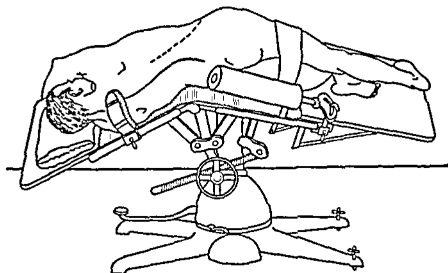


Figure 3 Posture of patient for thoraco-lumbar splanchnicectomy and sympathectomy (Reprinted from Griffiths H W C and Gillies J *Anaesthesia,* 1948 with the kind permission of the authors and the publisher)

in the region of the head and neck are performed in a reverse Trendelenburg position, in a head up tilt of up to 30 degrees or even (posterior fossa explorations) in the sitting position Many other forms of head and neck surgery (fenestration operation radical neck dissection, mandibular resection) have also required reverse Trendelenburg semi Fowler s or a head up tilt position Side tilt of the table and some degree of hyperextension have been employed for radical mastectomy while a true lateral jack knife position has been ideal for intra thoracic operations and combined thoraco lumbar splanchnicectomy and sympathectomy (Figure 3) For upper abdominal surgery,

by contraction of the limb muscles (368) When the operative site is superior to the rest of the body, however, these factors combine with the effect of gravity to enhance venous drainage away *from the area of surgical intervention* and to decrease the amount of bleeding in the wound

It is necessary also to consider the effect of posture upon arterial pressure a factor which generally has been disregarded in the past Enderby has attempted to demonstrate that *local* blood pressure in the wound is reduced 30 mm Hg for every 15 inches of vertical height of the operative site above the level of the heart (125) This is undoubtedly an over simplification of a very complex hemodynamic situation but it brings out the point that, above the level of the heart gravity opposes the hydrodynamic factor in the arteries, while, conversely, below heart level the hydrostatic and hydrodynamic factors are additive in those vessels

It has been shown that these effects of posture become exaggerated during controlled hypotension conducted by means of a reduction of peripheral resistance because of the marked increase in the capacity of the vascular bed following upon sympathetic blockade Thus, they may be a source of great danger inasmuch as reflex circulatory activity mediated through receptors in the carotid sinuses aortic arch, and the cardio aortic sinus is obtunded under the circumstances of complete sympathetic blockade and positions which impose a marked anti gravitational factor upon venous return may jeopardize the life of the patient (160) For this same reason however, one can vary the level of the patient s blood pressure by the simple expedient of lowering or elevating a leg an arm or even a hand this method of controlling the degree of the hypotension is a most important one in these techniques

The position in which the patient is placed for operation under controlled hypotension will therefore depend

requirements of cerebral metabolism, and there are a number of workers who refuse to employ controlled hypotension with the head above the level of the horizontal for this very reason. There is the added risk of air embolism in the head up position if large veins are encountered in the field of operation and are inadvertently entered during conditions of venodilatation and hypotension. Other anesthetists have condemned the head-down position because of the possibility that the profound passive congestion of the cerebral vessels during this posture may predispose to thrombus formation (311). The prone and lateral jack knife positions also have been indicted (274), since when the peripheral vascular bed is fully dilated and the inferior vena cava is above the level of its contributory veins venous return may be diminished to a point that is incompatible with continued circulation

Mention has been made already of the profound reduction of venous return and resultant severe hypotension, that may occur with changes in the patient s posture during complete sympathetic blockade and this point applies post-operatively to the same extent that it does during the operation itself since the closure of the skin incision does not necessarily coincide with the termination of sympathetic blocking activity Shifts in the patient s posture must be controlled carefully in the post operative period particularly when the legs are lowered from the lithotomy position, or when the patient is moved from the operating table transported on a stretcher or placed into bed

hyperextension with a raised gallbladder bridge has been used, the hyperextension of the spine in this position probably combining with the use of the bridge to compress the inferior vena cava and so to contribute to the degree of hypotension (124) This is true also of the lateral jack knife position, which has been employed for operations upon the kidney, when the highest point has been just below the thoracic cage The supine jack knife, or a 30 degree Trendelenburg position has provided good working conditions for radical pelvic or abdominal surgery (58) Operations such as repair of the pelvic floor or combined abdomino perineal resection have been difficult problems from the point of view of producing a bloodless field but blood loss can be diminished considerably by the use of the lithotomy position in conjunction with a steep head down tilt (391) A steep head down tilt alone has been used for operations upon the lower extremities but because there appears to be a more sensitive (to ganglionic blockade) sympathetic innervation to the lower extremities than to the upper part of the body better control of bleeding is possible when the site of operation is above the pelvis and legs (440) These examples suffice to show that in general the posture employed for a specific operative intervention conducted under the conditions of 'controlled hypotension is apt to be closely akin to that which empirical experience had taught many years ago was the most practical position for that particular surgical procedure

There are dangers associated with the positioning of the patient in controlled hypotension of which it is necessary to take cognizance Certain postures threaten ischemia to vital organs particularly the brain because induced hypotension and gravity may combine to lower the *local* blood pressure (as quite distinct from the blood pressure at heart level) below that necessary to fulfill the

neurosurgical interventions might lessen hemorrhage and so expedite operation, following which the patient could be reinfused with his own blood to reestablish normotension

Arteriotomy Arteriotomy, as developed by Kohlstaedt and Page (255), appeared to be such a technique, and Gardner therefore induced a relative hypotension in a patient undergoing excision of an olfactory groove meningioma, a large and vascular tumor, to test his theory A cannula was placed in the dorsalis pedis artery and connected with a reservoir flask, heparin and sodium citrate being employed to prevent clot formation within this system The pre-operative withdrawal of 1 600 cc of blood served to lower the systolic pressure from 140 to 100 mm Hg, and at the same time increased the pulse rate to 140 beats per minute It was Gardner s distinct impression that bleeding was greatly reduced during the operative procedure itself and the removal of the tumor facilitated to that extent At the end of operation prior to the closure of the wound 1,100 cc of the withdrawn blood was reinfused through the arterial cannula this reinfusion served to raise the systolic pressure from 90 to 120 mm Hg and caused some bleeding from the scalp incision though none from the tumor bed The patient s convalescence was uneventful Gardner stressed the fact that the peripheral vasoconstriction which accompanies loss of blood volume was chiefly responsible for the hemostasis and was far more important in this respect than the actual reduction of the arterial pressure

The use of the technique of arteriotomy and reinfusion to lessen the extensive bleeding that occurs during craniotomy performed for removal of vascular lesions was extended by Hale to include the fenestration operation in which bleeding is not large in amount but rather vexatious and capable of preventing a successful result should

VI

Reduction of Circulating Blood Volume

IN THE COURSE of investigating Seeley's suggestion that the intra arterial infusion of blood or plasma might have advantages over the conventional intravenous route in the treatment of shock (255), Kohlstaedt and Page developed an ingenious method for studying the shock syndrome by means of arterial bleeding and subsequent reinfusion Essentially, this technique consisted of cannulating the femoral artery in a direction toward the heart and then connecting the cannula to a closed reservoir into which the subject might be bled until the blood pressure had been reduced to the desired level The blood was mixed with an anticoagulant during its withdrawal and could be reinfused into the femoral artery in order to restore the blood pressure toward normal through the simple expedient of raising the pressure in the closed reservoir by pumping air into it

Gardner adapted this experimental method of arterial bleeding and reinfusion to the clinical problem of brain tumor surgery (149) He had noted that the hazards and difficulties of excising certain extremely vascular growths abated considerably as the operation wore on the blood loss increased in amount and the blood pressure fell to hypotensive levels at that point hemostasis was effected more readily and the remainder of the tumor was removed quite easily For a number of years he had pondered a technique whereby the withdrawal of blood prior to

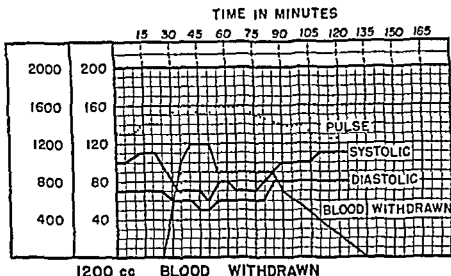


Figure 5 Arteriotomy for craniotomy The effect of the withdrawal of 1200 cc of blood upon the pulse and blood pressure is shown (Reprinted from Hale D E *Anesthesiology* 1948 with the kind permission of the author and the publisher)

degree of hemostasis was regarded as satisfactory on an average, this required the withdrawal of 1750 cc of blood over the course of half an hour If at any time during the bloodletting or the operation itself there was a further fall in arterial pressure blood was returned immediately to the artery from the reservoir under a pressure of 100 to 200 mm Hg until a systolic level of 80 mm Hg or higher had been regained At the end of the operation, when the need for hemostasis had passed but before the wound had been closed the withdrawn blood was reinfused by both artery and vein (Figure 5) However, since after the removal of a liter or more of blood from the vascular bed, the blood volume tends to increase from its low initial level due to the entrance of tissue fluids into the circulation at a rate which will compensate for the loss of 500 cc of blood in an hour the last 500 cc of withdrawn blood

it occur during the critical maneuver of shaping the fenestra and preparing the skin flap from the auditory canal (196) He used an apparatus which was a modification of that employed by Gardner (Figure 4) and the radial artery—which he ligated at the termination of the procedure—as the site of arterial puncture Blood was withdrawn rather rapidly at the beginning of surgery until a systolic pressure of 80 mm Hg was reached, or until the

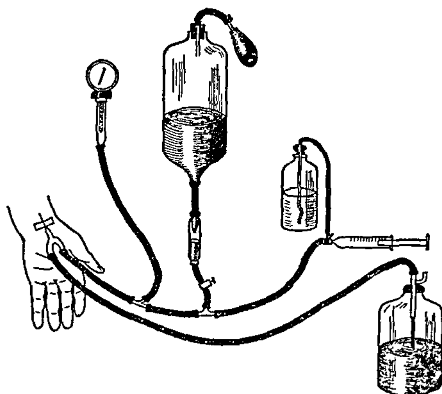


Figure 4 Apparatus for arteriotomy The Y shaped glass cannula is secured in the radial artery The lower tubing leads directly to the blood collecting flask The upper tubing leads to a manometer for reading the pressure in the radial artery or in the Kelly flask by means of which the blood may be returned to the patient under pressure The small flask and syringe contain a supply of 0 01% heparin solution (Reprinted from Hale D E *Anesthesiology* 1948 with the kind permission of the author and the publisher)

of controllability, both of the arterial pressure as well as the total blood volume (48, 150, 163) that is not possible with most other techniques of controlled hypotension When reinfusion is necessary, the intra arterial route is by far the most efficient method for raising the blood pressure rapidly (165), particularly in the presence of shock and myocardial ischemia due to decreased aortic pressure (353, 500) Furthermore such reinfusion of the patient s own blood instead of replacing the loss with the blood of one or more donors, not only conserves blood, but also avoids the risks of transfusion reactions or the development of homologous serum jaundice.

Finally, the reduction of both the total blood volume and the arterial pressure has an important advantage for intracranial surgery the tension of the brain is greatly reduced which facilitates retraction during difficult expo sures and increases the ease with which congenital aneu rysms and other deep seated lesions may be approached (48 295 333)

Despite these advantages however there are several dis advantages to the use of arteriotomy The major drawback of this technique of course stems from its *modus operandi* —vasoconstriction The combination of both a reduced total circulating blood volume and the compensatory vaso constriction which this induces approximates a state of hemorrhagic shock During such hypovolemic hypoten sion the ability of the organism to withstand even a minute blood loss is obtunded and the danger of circula tory depression passing into an irreversible stage is con stant (48) In this connection furthermore it must be emphasized that blood pressure recordings are not an en tirely reliable index of either the state of the peripheral circulation or of the imminence of the phase of irreversi bility (517) Even in the absence of an irreversible phase of circulatory depression however there is still the grave

was not administered but was banked and held in reserve for the patient

Other workers have added certain refinements to the technique (27, 48, 229, 295 333) but in essence arteriotomy has been employed in the manner just described The apparatus has been modified to provide a closed rather than an open system and the heparin has been administered by a slow continuous drip in an attempt to prevent the formation of small thrombi which occurred when heparin was administered by intermittent injections (333) The use of arteriotomy has been confined almost entirely to neurosurgical procedures (i e, craniotomy) and the fenestration operation (27 48, 149, 150, 151, 229, 295 333) although recent experimental results indicate that the method may be of great aid in operations upon the open heart and in major hepatic resections (55)

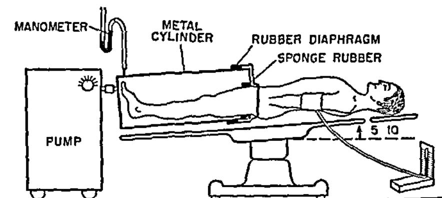
Arteriotomy offers certain well defined advantages as compared to other techniques of controlled hypotension' First and most importantly there is the very obvious hemostatic effect which renders blood loss less severe and thereby facilitates operation to a marked degree This hemostasis is due apparently to the generalized vaso constriction neurogenic in origin which has been shown to be the initial response to bloodletting (255) during the brief stage preceding shock a specific enzyme is believed to be liberated into the plasma which causes this compensatory vasoconstriction (351) Only as the blood volume is reduced further does there result a fall in blood pressure, which then also contributes to the hemostatic effect For this reason it is unnecessary to lower the blood pressure to dangerous levels in order to obtain a definite hemostasis (150) and bloodless operative fields can be achieved by removing only small amounts of blood (6)

A second great advantage of arteriotomy is the fact that repeated small bleedings and reinfusions permit a degree

of controlled hypotension,' despite its very real advantages in certain respects

Application of Negative Pressure to the Lower Extremities It has been recognized for a number of years that the amount of blood going to the lower extremities can be increased quite markedly by the application of negative pressure to the legs and thighs It has now been shown that this effect is increased considerably during sympathetic blockade with ganglionic blocking agents (387) Advantage has been taken of this fact to achieve a reduction of the *effective* circulating blood volume by trapping several hundred cc of blood in the legs and thighs during methonium induced hypotension by the use of a negative pressure device which applies pneumatic suction to the lower extremities (Figure 6) This technique has produced controlled hypotension in patients who were resistant to the hypotensive effects of the methonium compounds alone has permitted the use of smaller doses of methonium compounds and thereby helped to reduce postoperative hypotension, and has allowed a better control over the level of the blood pressure which can be raised or lowered promptly by decreasing or increasing the negative pressure applied to the legs (420 230)

danger of anoxic tissue damage, since the increased periph eral resistance produced by vasoconstriction necessitates higher arterial pressures, in order to maintain cellular respiration, than the low pressures which may obtain dur ing arteriotomy The fact that this theoretical danger has not materialized during the clinical series that have been

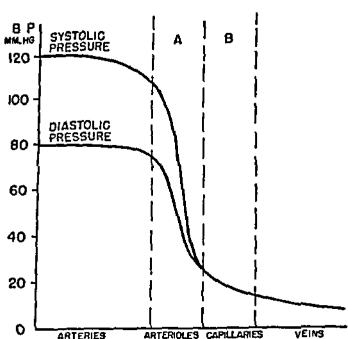


NEGATIVE-PRESSURE DEVICE SHOWING APPLICATION OF CYLINDER TO PATIENT'S LEG

Figure 6 Negative pressure device for enhancing methonium induced hypotension (Reprinted from Saunders J W *Lancet* 1952 with *the kind permission of the author and the publisher*)

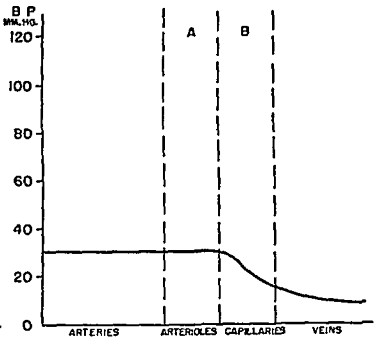
reported may be explained in part by the fact that this is the one type of controlled hypotension in which the circulatory reflexes remain active permitting blood to be shunted to vital organs

Certain other disadvantages should be mentioned the equipment is cumbersome and the technique itself is difficult and time-consuming to initiate the dangers of infection and air embolism both exist and have been encountered during the clinical performance of the method and the possibility of clot formation within the apparatus is ever present These disadvantages together with the phenomenon of vasoconstriction, have served to make arteriotomy the least popular of all the techniques



SYSTEMIC ARTERIAL PRESSURE GRADIENT IN NORMAL SUBJECT

A: SITE OF MAXIMAL PERIPHERAL RESISTANCE
B: SITE OF TISSUE RESPIRATION



SYSTEMIC ARTERIAL PRESSURE GRADIENT IN THE TOTALLY SYMPATHECTOMISED SUBJECT

A PERIPHERAL RESISTANCE REDUCED
B: NORMAL CAPILLARY PRESSURE SITE OF TISSUE RESPIRATION

VII

Reduction of Peripheral Resistance Conduction Anesthesia

PERIPHERAL resistance resides largely in the variably contractile arterioles and is maintained by the continuous stream of vasoconstrictor impulses arising from the brain stem and carried via the sympathetic nerves to the vessel walls themselves Interruption of this efferent sympathetic outflow results in arteriolar dilatation and thus effects a reduction of peripheral resistance The capacity of the vascular bed is increased thereby relative to the total circulating blood volume and this disruption of the finely adjusted balance between the two produces hypotension

It has been argued that a reduction of peripheral resistance is the most nearly physiological method presently available to induce hypotension for the purpose of achieving a bloodless operative field during surgical interventions (175) The pressure within the vascular tree normally is highest in the aorta and falls progressively as the blood flows through the large and small arteries to the arterioles (267) It is in the vast arteriolar network that the truly pronounced fall in pressure occurs (Figure 7) so that by the

→

Figure 7 The effect of arteriolar dilatation on the level of blood pressure necessary for tissue respiration (Reprinted from Griffiths H W C and Gillies J *Anaesthesia* 1948 with the kind permissions of the authors and the publisher)

which can be accomplished relatively simply, thus have become the methods of choice for the production of controlled hypotension by means of conduction anesthesia

Total Spinal Block The use of total spinal analgesia for surgical interventions has been practised intermittently by bold pioneers since the earliest days following Bier s initial demonstration of spinal analgesia in 1899 In 1900 Morton employed spinal analgesia to accomplish excision of the superior maxilla (334) and operations upon the head under spinal analgesia were reported by Payne as early as 1901 (370) Tait and Caglieri injected at sites as high as the cervical region to obtain total spinal analgesia (469) and Jonnesco utilized this method in over 100 operations above the level of the diaphragm (233) Le Filliatre also practised massive spinal analgesia, employing barbotage to achieve high levels of block (281) The hypotensive effects achieved by the techniques of these early workers were appreciated rather than understood Pitkin has stated In those days (1912) we knew little or nothing about pressure changes and our only common concern was whether we had anesthesia we used to marvel at the fact that we had such dry wounds (380)

Koster in the early 1920 s was an ardent advocate of total spinal analgesia and employed it intrepidly for such operations as mastoidectomy and thyroidectomy (258 259) He was thoroughly aware of the marked falls in blood pressure which occurred and approved of them because of the dry wounds that they produced in the non dependent portions of the body Bourne and his colleagues have established total spinal analgesia as a valuable method of anesthesia for chest surgery not least because of the great reduction in the amount of bleeding (56 190 191)

It is a matter of present day wonder, in view of the drastic nature of the techniques employed not that so

time that the blood has reached the capillaries the pressure is only 32 mm Hg This level of pressure is sufficient to maintain tissue oxygenation and cellular respiration The hypothesis has been put forward that, if the peripheral resistance is abolished by arteriolar dilatation, very low arterial pressures—32 mm Hg or above to be exact —should be adequate to maintain the tissue oxygenation and cellular respiration inasmuch as the energy of the blood column need no longer be expended in overcoming the frictional surface resistance of the arteriolar bed In other words the assumption has been made that under conditions of complete arteriolar dilatation and in the presence of a normal blood volume, normovolemic hypotension should be well tolerated by the organism without danger of tissue anoxia (175)

The vasoconstrictor fibers which maintain peripheral resistance belong to the thoraco lumbar (sympathetic) division of the autonomic nervous system, and arise from preganglionic cell bodies located in the intermediolateral cell column of all twelve thoracic and the upper three or four lumbar segments of the spinal cord The axons of these cells traverse the anterior roots pass to the trunk ganglia as white rami communicantes and are distributed thence to the peripheral vessels either in the outer coats of the large arteries or via the somatic nerve trunks Blockade of these fibers can therefore be effected by local anesthetic agents acting upon the ventral roots upon the rami communicantes or upon the sympathetic chain itself

It has been demonstrated that in order to induce a substantial fall in blood pressure it is necessary to block almost the entire efferent sympathetic outflow (89 205) Paravertebral and sympathetic chain blocks while theoretically feasible would require too many separate injections and would be too tediously time consuming to be practical Spinal or epidural (extradural) analgesia both of

paralyzed, and it has been shown that motor block requires the highest and vasomotor block the lowest concentrations of local anesthetic agent, sensory block occupying a somewhat middle position in this regard (Table IX)

Griffiths and Gillies took advantage of these facts to

TABLE IX

CONCENTRATIONS OF PROCAINE REQUIRED TO BLOCK VARIOUS TYPES OF NERVOUS TISSUE

Type of Nervous Tissue	*% of Procaine*
Vasomotor Fiber	0.2
Sensory Fiber	0.33–0.5
Motor Fiber	0.5 –0.75
Medullary Centers	1.25–1.8

contrive a differential spinal block in which there was motor and sensory paralysis to a level appropriate for the proposed operation but which in addition involved the whole sympathetic outflow and so produced a considerable fall in blood pressure (175) Since a concentration of 0.2% procaine suffices to paralyze preganglionic sympathetic fibers the phrenic nerves were not affected when the anesthetic solution becoming more and more dilute was allowed to diffuse into the cervical region of the cord They have termed this *total spinal block*, which they differentiated from *total spinal analgesia* in that although the blood pressure was reduced to a level of 70 mm Hg or below by blockade of the entire sympathetic outflow, lesser degrees of sensory and motor block obtained and therefore the muscles of respiration remained relatively unaffected (160 161, 175)

The basic features of *total spinal block* as evolved by these workers (Figure 8) have consisted of a minimal injection of pentothal to induce hypnosis, the establishment of high spinal block by 150 to 300 mgm of procaine or 1 5

few patients succumbed during these early trials but that any survived at all (175) The surgeon of the era which marked the beginning of the century worked without benefit of the knowledge of the dangers of anoxia or the facilities with which to combat respiratory failure The relatively low mortality that pertained has been ascribed to the fact that anhydrous cocaine was employed and paralyzed the sensory roots but left the motor roots rela tively unaffected by the weaker concentrations which reached the upper spinal segments For it has now been well established that death under spinal analgesia results primarily from peripheral respiratory paralysis (131 482) As the level of anesthesia rises into the thoracic region, the intercostal nerves are paralyzed and respiration becomes entirely diaphragmatic and hence slow and of small am plitude Further ascension of the level of anesthesia into the cervical region paralyzes the phrenic nerves and causes respiratory failure

The comportment of the blood pressure during spinal anesthesia has also been the subject of intensive investiga tion (89 205) Vasodilatation sufficient to effect a reduc tion of arterial pressure occurs only after the highest thoracic segments have been paralyzed due to the fact that with lesser degrees of blockade intense compensatory vasoconstriction occurs in those parts of the body to which the sympathetic outflow remains intact (343) It has been recognized for some time that it is possible to produce subarachnoid block of sensory fibers that is accompanied by little or no motor paralysis (16) and that when either cocaine (204) or procaine (411) is deposited around a mixed nerve blocking of all fibers does not occur simul taneously The technique of differential spinal block which was developed by Sarnoff and Arrowood (17, 411, 412 413 414) has been employed to investigate the se quence in which the various types of nerve fibers are

vis a tergo (already considerably reduced) be incapable of coping with the additional load Venous return could be improved, whenever clinical assessment of the state of the circulation dictated, by altering the patient's position (particularly by raising the legs, or tilting the table into Trendelenburg or reverse Trendelenburg, as the situation required) or by abolishing the vasodilatation by the use of vasoconstrictor agents which act peripherally As the vaso constrictor paralysis passed off normotension was reestab lished if this did not occur prior to closure a vasocon strictor (methedrine) was employed to reveal potential bleeding points The converse problem that of reestab lishment of normotension too early in the course of opera tion may be circumvented by the use of the continuous spinal technique with intermittent injections of the local anesthetic agent being made as required (173 474) Post operative care must be meticulous with particular atten tion being paid to the maintenance of a 20 degree head down position for the first eight hours

As compared to other methods for the production of controlled hypotension *total spinal block* boasts certain well-defined advantages When the technique is conducted properly and the dosage of the local anesthetic agent for intrathecal administration has been estimated correctly, a profound fall in blood pressure and an extremely ischemic field can be produced in almost all instances Furthermore this is achieved by paralysis of the sympathetic outflow only whereas blockade produced by chemical ganglionic blocking agents acts upon both parasympathetic and sym pathetic ganglia and so introduces other complicating factors Finally high spinal block is part of the anesthetic technique itself, and so acquires a double usefulness, in that it produces motor and sensory paralysis in addition to the sympathetic blockade In this connection it must be emphasized that to obtain the fullest benefits from

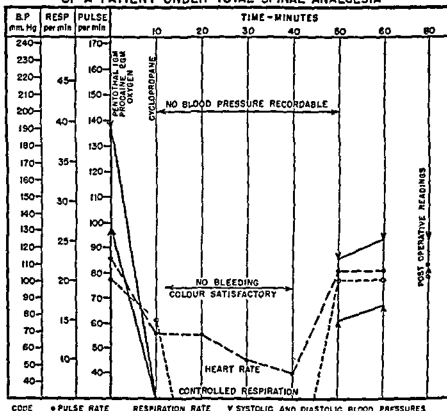


Figure 8 Anesthetic record of a patient under *total spinal block* (Reprinted from Griffiths H W C and Gillies J *Anaesthesia,* 1948 with the kind permissions of the authors and the publisher)

to 3 0 mgm of nupercaine administered intrathecally and maintenance of light general anesthesia with nitrous oxide The patient was positioned meticulously to permit the operative site to remain superior so that bleeding was minimal and the patient s blood volume remained con stant Since there was generalized arteriolar and post arteriolar dilatation with considerable pooling of blood in the dependent portions of the body emphasis was made of the fact that the anti gravitational resistance to venous return must not be allowed to be too great, lest the arterial

vis a tergo (already considerably reduced) be incapable of coping with the additional load Venous return could be improved whenever clinical assessment of the state of the circulation dictated, by altering the patient s position (particularly by raising the legs or tilting the table into Trendelenburg or reverse Trendelenburg, as the situation required) or by abolishing the vasodilatation by the use of vasoconstrictor agents which act peripherally As the vaso constrictor paralysis passed off, normotension was reestab lished if this did not occur prior to closure, a vasocon strictor (methedrine) was employed to reveal potential bleeding points The converse problem that of reestab lishment of normotension too early in the course of opera tion may be circumvented by the use of the continuous spinal technique, with intermittent injections of the local anesthetic agent being made as required (173, 474) Post operative care must be meticulous, with particular atten tion being paid to the maintenance of a 20 degree head down position for the first eight hours

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spinal block it is necessary to ensure sympathetic paralysis to a high level even if the sensory and motor blocks are restricted to the segments supplying the operative field since otherwise the compensatory vasoconstriction occurring in the distribution of the unblocked sympathetic fibers may actually increase rather than reduce, bleeding

Granted, however, that a low head of arterial pressure associated with vasodilatation and a normal blood volume carries less theoretical danger than illusory higher arterial pressures accompanied by vasoconstriction and a reduced blood volume controlled hypotension produced by spinal anesthesia still carries with it those inherent capacities for catastrophe which have become the hallmark of these techniques Furthermore, the usual disadvantages associated with spinal analgesia such as headache sepsis, and the like still apply The technique lacks the controllability that is obviously desirable and found to some degree with certain ganglionic blocking agents (i e arfonad see Chapter VIII) Finally when a spinal block has been administered to a sufficiently high level to permit upper abdominal or mid abdominal surgery assisted respirations may be necessitated by a diminution of respiratory exchange, and this maneuver by increasing intrapulmonary pressure and therefore venous back pressure may actually cause an increase in vascular ooze and defeat utterly the objective of the technique

Epidural Block Epidural analgesia has been advocated for the control of hypertension in eclampsia and the toxemic states of pregnancy on numerous occasions during the past decade but only recently has it been utilized to produce intentional hypotension during surgical procedures (62, 63 114) Indeed one of the major advantages ascribed to epidural analgesia in the past has been the absence of effect upon blood pressure This is of course true only if the block is truly segmental and the number of seg

ments blocked are few in number However, if the block extends over the lumbar outflow and well up into the thoracic segments, sufficient sympathetic fibers are paralyzed to result in a profound fall in arterial pressure (89, 205)

Bromage has been a leading exponent of this method for producing controlled hypotension " and has patterned his technique closely after *total spinal block* as developed by Gillies, extradural block being substituted for the subarachnoid block (62, 63) The advantages cited include all those attending spinal block, but without the inherent dangers of headache meningismus and the like There *remain the disadvantages of the greater difficulty in performing* epidural block as compared to the performance of lumbar puncture the admitted inability to prejudge the effective height of an epidural block with the same degree of accuracy as a subarachnoid block, the grave hazard of massive subarachnoid injection the possibility of infection of the epidural space and a failure rate of 1 4% (even in obviously expert hands) (63)

One novel method of controlling bleeding in the operative site by the use of epidural analgesia has been the establishment of partial sympathetic blockade, sufficient to induce a mild hypotension, but insufficient to prevent an intense compensatory vasoconstriction in the upper part of the body (343) This combination of generalized hypotension and localized vasoconstriction in the operative site has been exploited particularly in the fenestration operation and other forms of cranial surgery (168)

VIII

Reduction of Peripheral Resistance. Ganglionic Blockade

PERIPHERAL resistance can be reduced by interrupting the continuous flow of vasoconstrictor impulses to the arterioles at any point in their route Of all the methods for inducing hypotension by the reduction of peripheral resistance the use of ganglionic blocking drugs has proved to be by far the most popular technique in the production of controlled hypotension (see Table VIII), due in large measure no doubt to the fact that the administration of these agents requires merely a simple intravenous injection

Certain generalizations can be made concerning the use of these drugs They are not anesthetic agents in themselves although clinically the hypotensive state does seem to be associated with a need for less general anesthesia than normal These autonomic ganglionic blocking agents paralyze both parasympathetic and sympathetic ganglia thus introducing undesirable complicating factors in certain instances Finally, the failure rate (that is the failure to produce hypotension) is often high when these drugs are employed for that purpose much higher than that encountered in the use of either arteriotomy or the various methods of conduction anesthesia that are utilized to reduce peripheral resistance

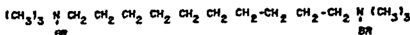
The Methonium Compounds Pentamethonium and hexamethonium are respectively the five and six carbon

atom homologues of the polymethylene series of methonium compounds (Figure 9), the pharmacological properties of which were described by Paton and Zaimis in 1948 (363) The ten carbon atom homologue, decamethonium,

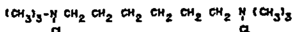
THE METHONIUM COMPOUNDS

POLYMETHYLENE BIS TRIMETHYL AMMONIUM COMPOUNDS

DECAMETHONIUM



HEXAMETHONIUM



PENTAMETHONIUM

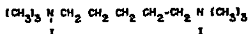


Figure 9 The methonium compounds

which has a potent myoneural junction blocking activity (350) has achieved widespread use for the production of skeletal muscle relaxation during clinical anesthesia (348) Pentamethonium and hexamethonium on the other hand do not block the myoneural junction to any such significant degree but do inhibit transmission of nervous impulses through the autonomic ganglia of the sympathetic and parasympathetic nervous systems (364) These potent and specific ganglionic inhibitors apparently act to paralyze ganglionic transmission by raising the threshold of the ganglion cell to acetylcholine released at the preganglionic nerve endings (365) It is this blockade or inhibition

of ganglionic transmission which is responsible for the major pharmacological properties of penta and hexa methonium vasodilatation fall in blood pressure, and an increase in blood flow and elevated skin temperatures in the extremities (14 15 71, 177, 423, 472), inhibition of intestinal peristalsis, inhibition of gastric secretion and reduction of gastric motility (108, 237, 238), inhibition of salivary secretion (472) and dilatation of the pupils together with some disturbance of accommodation of the eye

Clinical application of these pharmacological properties has been made by the employment of the methonium compounds for the treatment of gastric and duodenal ulcer (237 238 433), peripheral vascular disease (71, 136 137, 146 427) acute ventricular failure (499), intractable hiccup (212, 301 302) toxemias of late pregnancy (330 374 473) and most importantly hypertension (74 93 143 305 307 386, 431 453, 455) The administration of these drugs in the medical therapy of the various hypertensive states has brought to light a number of points of some importance in connection with their use in the production of controlled hypotension in anesthesia and surgery

It is now generally accepted that although both penta and hexa methonium will produce vasodilatation and a fall in blood pressure the six carbon homologue is probably the more predictable and dependable of the two in this regard (74 140 456) however it should be pointed out that not all observers concur in this view (33) It must be recognized that tolerance may develop to these drugs and for this reason it may become impossible to maintain a satisfactory hypotension (142 252, 473) Indeed, individual resistance may obtain from the very commencement of therapy so that a significant fall in blood pressure is never achieved (30)

On the other hand prolonged hypotensive effects may

follow the use of these agents (495), particularly in the presence of kidney disease and impaired renal function, since these compounds are excreted almost quantitatively in the urine by both the experimental animal (513) and man (324) The mechanism of the renal excretion of the methonium compounds was studied by comparing the clearances of these substances with the simultaneous clearance of inulin, and from the methonium/inulin clearance ratios so obtained it was clearly evident that the renal excretion of methonium compounds is due mainly to glomerular filtration with only minimal tubular excretion (512) Therefore, even in the absence of renal disease, methonium induced hypotension may decrease glomerular filtration sufficiently to delay excretion of the drug and thus produce a vicious cycle of prolonged activity (306 308) There is also the further danger of bromism or iodism (217, 287, 361 392, 460) if renal function is abnormal or if large doses of either of these salts are employed over a prolonged period of time however, this hazard can be circumvented by the use of the bitartrate or chloride preparations (75)

Finally there is the every grave problem of dosage, and especially of initial dosage (30) for the individual variation in response to a given dose of these substances is immense (142, 144 289), varying not only between patients but also in the same patient at different times (499) On the one hand this may make a satisfactory therapeutic response to the administration of these drugs difficult or even impossible to attain (252 289 341) and on the other hand a sudden and extreme hypotension may be induced and result in pathological damage to vital organs (213 454), particularly when vascular sclerosis already exists

Penta and hexa methonium were employed first in anesthesia as antidotes to the muscle relaxant decamethonium (350) before the hypotensive effects of these com

pounds were generally appreciated It became apparent immediately that these drugs produced a profound fall in blood pressure when administered to the anesthetized patient (227) and that they should not be employed as antagonists to myoneural blocking agents for this reason However, this hypotensive effect was seized upon immediately as the basis for a technique of controlled hypotension' (98, 120), and the success achieved thereby led rapidly to the extensive use of the methonium compounds for the medical therapy of hypertension (74 93 143 305 307 386 431, 453, 455)

The administration of methonium compounds to induce hypotension for the reduction of bleeding during operative interventions has now become exceedingly widespread (18 19, 59 78 79 96 110, 123, 124, 126, 127, 211 214 224 231, 239 248 274 279 285 291 303 315, 340 347 349 373 390 399 435 440 465, 479 491 494 502) A number of different techniques have been developed by the many workers who have employed the methonium drugs to induce hypotension but these techniques differ mainly in details and minutae The broad general plan of the majority of these techniques is similar to that illustrated in Figure 10/ The anesthesia is induced by the administration of intravenous pentothal intubation is performed (a muscle relaxant usually being employed to facilitate this maneuver) and anesthesia is then maintained with an inhalation agent (nitrous oxide cyclopropane ether or trichlorethylene (98 120 127) The methonium salt is then administered intravenously to produce hypotension hexamethonium is more consistent in achieving this effect and for that reason enjoys a greater vogue than the pentamethonium homologue (19, 59, 79 127 214 231 239 279 303 491 494 502) Two schools of thought have developed regarding dosage one group of workers feels that a large (50 to 100 mgm) initial dose is

necessary to achieve blood pressure levels of from 55 to 65 mm Hg, which will persist for from 40 to 60 minutes, (127) while a second group feels that much smaller doses (5 to 30 mgm) can be administered every 20 to 30 minutes

MEMORIAL HOSPITAL
ANESTHESIA RECORD

Figure 10 Anesthesia record of hexamethonium hypotension (Reprinted from Boyan C P and Brunschwig A *Surgery* 1952 with the kind permissions of the authors and the publisher)

as the clinical conditions warrant (59, 462) The rationale behind this latter technique has been carried to its logical conclusion by a few who have employed hexamethonium in a dilute intravenous infusion (274, 394) A certain group of patients (about 15%) are resistant to the effects of the methonium compounds it is usually young and robust individuals who fall into this category (126) Another, smaller number of patients develop resistance to repeated doses and it is for this reason that some workers feel that the initial dose must be large enough to achieve the desired fall in pressure, for the required duration of time without recourse to repeated administration (127)

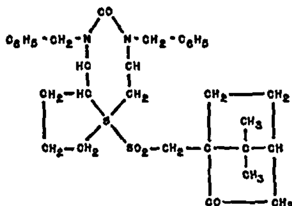
Following the initial fall in blood pressure the patient is positioned so that the operative site will be superior to the other portions of the body, and this maneuver usually provides a further reduction of the systolic pressure due to pooling of the blood in the dependent portions of the *dilated vascular system (71) Operation is then begun* Bleeding is usually minimal, but all the blood that is lost must of course, be replaced *in toto* Operation generally proceeds with dispatch and the operative time is diminished to a considerable extent There is a marked difference of opinion concerning the desirability of employing vasoconstrictor agents at the end of operation for the purpose of raising the pressure and revealing potential bleeding points prior to closure of the wound (197, 198) the argument against the use of these drugs is that clots and thrombi which have formed in the cut dilated vessels will be retained in situ if the vessels gradually regain tone and contract down about the formed clots whereas sudden increases of intravascular pressure produced by vasopressor drugs will tend to blow out such clots (see Chapter IX)

Post operative care must be meticulous perhaps more so with this technique than with other forms of controlled hypotension for the methonium compounds may have

prolonged effects upon vessels, making changes in the patient's position dangerous for several hours after their administration, even though the blood pressure has re turned to normal when the patient is in the horizontal position (71)

Arfonad Arfonad, a thiophanium compound with po

ARFONAD



d-3,4 (1',3' DIBENZYL 2'-KETO-IMIDAZOLIDO)-1,2-TRIMETHYLENE THIOPHANIUM d CAMPHOR SULFONATE

Figure 11 Arfonad

tent ganglionic blocking activity (384) has afforded the anesthesiologist a more controllable method of inducing hypotension by means of reduction of the peripheral resistance than can be attained by either conduction anes thesia or the use of the methonium compounds (344) Chemically this drug is d 3 4 (1 3 dibenzyl 2 ketoimida zolido) 1 2 trimethylene thiophanium d camphor sulpho nate (Figure 11) It apparently has direct vasodilator

properties as well as potent ganglionic blockading activity (300) and single intravenous doses of 0.1 or 0.2 mgm per kgm of body weight will produce a prompt but evanescent depressor response of the arterial pressure (417). Thus it is possible to employ the drug by a continuous intravenous infusion technique to provide graded and rapidly reversible falls in arterial pressure. It has been administered in this manner in the treatment of acute pulmonary edema in hypertensive crises (95, 410, 415, 416, 417, 418, 419) to control sympathetic overactivity in ulcerative colitis (511), and in the management of hypertensive complications of pregnancy (22). The mechanism responsible for arfonad's very brief action is poorly understood but there is evidence that at least 30% of the compound is excreted in the urine, apparently unchanged, with great rapidity (156).

The use of arfonad in controlled hypotension during surgical interventions has been by the continuous infusion technique, and has provided a degree of control over the level of the blood pressure on a minute to minute basis that has not been obtainable with other methods of induced hypotension. The anesthetic techniques and management have been very similar to those employed when hypotension is achieved by the administration of the methonium compounds (4, 28, 76, 102, 113, 218, 251, 286, 310, 329, 400, 401, 402, 403, 437, 489).

One innovation made possible by this drug, however, has been the development of a modified technique of controlled hypotension (286). This modified concept has been based upon two important facts. First, that the level of the systolic arterial pressure necessary to produce a relatively bloodless operative field varies tremendously between individual patients and therefore the exact level to which the pressure must be lowered cannot be foretold with any degreee of accuracy prior to actual operation. This knowledge can be obtained only after suitable pos

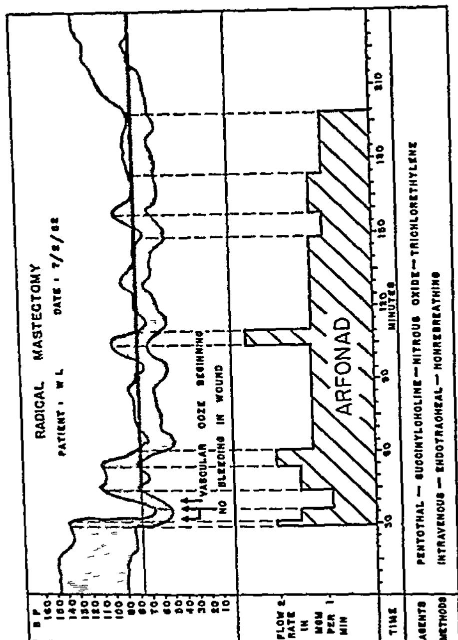
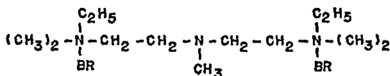


Figure 12 Anesthetic chart of modified technique of arfonad induced hypotension (Reprinted from Little D M Jr Hampton L. J and Grosskreutz D C *Surgery* 1954 with the kind permission of the publisher)

turing of the patient and direct observation of the bleed ing—or lack of it—in the operative field itself Second this level of optimal pressure is often much higher than the dangerously low pressures (50 to 60 mm Hg) often advocated in the past Indeed a significant reduction in

PENDIOMIDE

CIBA 9295



PENTAMETHYL-DIETHYL-3-AZA-PENTANE-1,5-DIAMMONIUM DIBROMIDE

Figure 13 Pendiomide

blood loss is frequently noted at pressures of 90 to 100 mm Hg and this may represent only a 10 to 20 mm Hg de crease in pressure from the pre operative normal Under such circumstances the benefits of controlled hypoten sion become available to the patient at less risk of major sequelae

In this modified technique (Figure 12) following the completion of anesthetic induction and proper posturing of the patient the arfonad infusion in a 0 1% concentra tion is started and run at a sufficiently rapid rate to evoke a substantial fall in arterial pressure As the pressure is being lowered, repeated blood pressure readings are corre lated with the degree of vascular ooze visible in the wound in order to ascertain the all important level of pressure

which will provide control of excessive bleeding during operation The infusion rate is then regulated to maintain this blood pressure throughout that part of the operation during which it is desirable to control the amount of

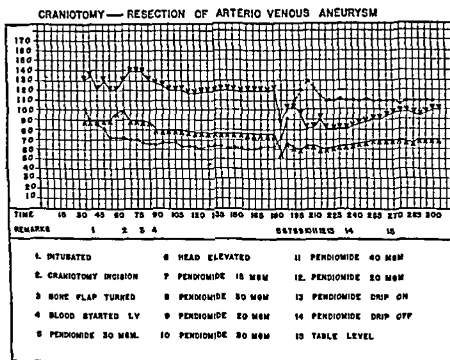


Figure 14 Anesthetic record of hypotension induced with pendiomide (Through the kind courtesy of Dr C R Stephen)

bleeding At the end of surgery or in the event of hemorrhage or similar surgical exigency normotension can be restored rapidly by merely discontinuing the infusion

Arfonad is not quite the panacea for controlled hypotension however for even this admirable drug has certain disadvantages such as the development of tachyphylaxis the occasional onset of tachycardia under its effect and rarely prolonged hypotensive effects

Pendiomide A third method of chemical ganglionic blockade for the purpose of lowering peripheral resistance

has been by the administration of the diethylenetriamine derivative, pendiomide (188) This drug, chemically is N,N,N',N',3 pentamethyl N N' diethyl 3 aza pentane 1 5 diammonium dibromide (Figure 13) and it has been shown to have marked ability to inhibit the synaptic trans mission of impulses through autonomic ganglia (37 38 44 262, 294, 314) Pendiomide has been employed for the reduction of intra ocular pressure in glaucoma (44) for the treatment of eclampsia (44), for the therapy of herpes zoster (346), for relief of bladder tenesmus during cystos copy (428) for the therapy of acute pulmonary embolism (91 429) and of course, for the production of controlled hypotension during surgery (24 41 80 106 155 187 188 189 235, 254 407 451 478 516)

The anesthetic techniques and management which have been utilized in conjunction with the use of this agent for the production of controlled hypotension have been very similar to those described for methonium or arfonad induced hypotension (Figure 14) A single intravenous injection of pendiomide has an acute effect of five to 10 minutes duration complete recovery occurring in about 30 minutes Pendiomide is therefore somewhat between the methonium compounds and arfonad as far as duration of activity is concerned and the average dose necessary to achieve an optimal hypotensive effect is between 50 and 100 mgm administered at the rate of 10 *mgm per min ute* Its advantages include high specificity of action and low toxicity while its major disadvantages are the facts *that the dosage is unpredictable and that some patients* are resistant to the effects of the drug It appears to be less controllable than arfonad although more controllable than the methonium compounds

IX

Physiological Considerations

GILLIES has referred to the techniques of induced hypotension during anesthesia as physiological trespass (161) and there can be no doubt that they frequently do exceed the bounds of physiological rectitude It has been a source of considerable amazement that so many anesthesiologists and surgeons trained to abhor and combat any deviation from normotension, should so suddenly embrace the reactionary philosophy of deliberate hypotension A source of even greater amazement has been the fact that they have done so in the face of a glaring lack of fundamental investigation into the profoundly disturbed physiology that is inherent in these techniques It would seem imperative that those employing controlled hypotension should understand fully the nature of the physiological derangements so produced particularly as to the state of such vital organs as the heart the brain the liver and the kidneys

The Level of the Blood Pressure The levels of the blood pressure sought (but presumably not always attained) in 27 930 cases conducted under the techniques of controlled hypotension (197 198) are recorded in Table X It is worth noting that these blood pressures low as they may seem in many instances were in all probability even lower in actual fact Woodhall and his associates have demonstrated a significant variation between the pressure readings obtained by the arm cuff method and the actual systemic intravascular pressure as recorded by a Sanborn electromanometer from the cannulated radial

artery during controlled hypotension produced by ganglionic blocking drugs The arm cuff method showed an average fall of 34 6% in blood pressure under these conditions, whereas simultaneous strain gauge recordings indi

TABLE X

THE LEVEL OF BLOOD PRESSURE SOUGHT IN 27 930 CASES OF CONTROLLED HYPOTENSION

Blood Pressure Level	*Great Britain and Ireland 21,125 Cases*	*U S A 6,805 Cases*	*Grand Total 27,930 Cases*
60 Mm Hg or Less	4,571	329	4 900
No Fixed Level but Above 60 Mm Hg		968	968
Pre operative Diastolic Level		50	50
60–80 Mm Hg	6 847	2,588	9 435
70–80 Mm Hg	5 727	166	5 893
80 90 Mm Hg	1 392	2 664	4 056
90 Mm Hg	666	3	669
100 Mm Hg	232		232
Not Stated	1 690	37	1 727

(Reprinted from Little D M Jr *Induced hypotension in anesthesia and surgery* *Anesthesiology* *16* 320 1955 with the kind permission of the publisher)

cated an actual fall of 52 9% in radial arterial pressure (507)

Low levels of arterial pressure are undoubtedly seldom physiological when accompanied by vasoconstriction, but a considerable body of evidence has been presented to support the contention that hypotension *per se*, is not necessarily a dangerous phenomenon if brought about by arteriolar dilatation and without loss of circulating blood volume Phemister and his co-workers have shown that reduction of the systolic blood pressure in rabbits to 25 to 40 mm Hg produced by stimulation of the aortic depressor nerve could be maintained for a far longer time without lethal outcome than an equal reduction of pressure produced by hemorrhage (379) Dale and Laidlaw

found that a carefully adjusted infusion of acetylcholine could produce dilatation of the cat s arterioles and lower the blood pressure to 30 to 40 mm Hg , although the veins remained well filled and the venous return to the heart was normal, on the other hand when a similar reduction of pressure was produced by a slow infusion of histamine, the venous return failed and the blood was found to be in the engorged capillary bed (94) a condition which Moon has described as irreversible shock (328)

It seems evident from these animal investigations, as well as from comparable observations during many thousands of clinical experiences with the techniques of controlled hypotension that the mammalian organism can indeed survive prolonged periods of profound hypotension produced by arteriolar dilatation and undoubtedly can do so under such circumstances far more often than it can survive a similar hypotension produced by either capillary dilatation or hemorrhage The interesting question arises however as to the effect of such low pressures upon the organism itself when it does survive and the role that these hypotensive levels of blood pressure may play in producing mortalities in those who fail to survive

Effects on the Cardiovascular System Studies of the pulse rate during operations performed under high spinal analgesia have usually revealed a definite bradycardia (296 297 409) whereas hypotension induced by a ganglionic blocking agent was more likely to be accompanied by a relative (285) or definite (390) tachycardia The discrepancy between these effects of controlled hypotension upon the heart rate may be explained in part by the fact that the sympathetic blockade of high spinal analgesia evokes the Bainbridge reflex the lowered venous pressure within the great veins producing reflexly an increase in vagal tone a bradycardia and a prolonged diastole (175) whereas hypotension induced by ganglionic blocking

agents is accompanied by parasympathetic blockade in addition to the sympathetic blockade and in some individuals the former may predominate, with a resultant tachycardia

The stroke volume of the heart during operations performed under high spinal analgesia was reduced from an average control level of 57 3 cc to 28 3 cc and the cardiac output and cardiac index fell to 40% of the basal level (296 297 409) Studies of the cardiac output during hypotension induced by ganglionic blockade have shown conflicting results due in large measure to differences in the clinical conditions during the observations, particularly as concerns the degree of hypotension and the posture of the subject during the period of hypotension In the recumbent position cardiac output in the unanesthetized subject was usually well maintained (145 499) When however such patients were tilted from the horizontal to a foot down position a significant reduction of cardiac output occurred Cardiac output in surgical patients under conditions of controlled hypotension' induced by methonium compounds was reduced 53% on the average and as much as 75% in certain patients (445) Investigation of the cardiac output by ballistocardiography during arfonad induced hypotension likewise showed a diminished stroke volume although the accompanying compensatory tachycardia prevented marked alteration of the minute volume (401)

Measurements of right auricular pressure during high spinal block demonstrated a profound reduction (296 297 409) which would be expected in view of the fact that the venous pressure is greatly reduced and there is a marked diminution in venous return to the heart both after the induction of high spinal analgesia as well as following the administration of ganglionic blocking agents (185 427) Pulmonary arterial pressure was decreased

markedly also, as much as 34% following high spinal anal gesia (409) and to an even greater extent after the induc tion of hypotension with ganglionic blocking agents (162)

The oxygen consumption, *in the studies made of high* spinal analgesia, decreased an average of 33% but the arteriovenous oxygen difference rose from an average of 4 07 vol % to 6 79 vol % The oxygen saturation of the arterial blood was not significantly altered in spite of a slight decrease in the arterial oxygen capacity (which was due to an unexplained fall in hematocrit that amounted to 3 3%) (296 297, 409) The oxygen consumption in the cat made hypotensive by the administration of either arfonad or hexamethonium was likewise perceptibly re duced (369)

The calculated work of the left ventricle was decreased on an average of 85% from the control level (297 409) and led to a marked reduction of coronary flow in the surgical patient undergoing high spinal block (409) A similar decrease in coronary flow has been found in the experi mental animal made hypotensive by either the subdural injection of procaine or the intravenous administration of etamon (115), but more recent studies in anesthetized dogs with renal hypertension (experimental perinephritis) made hypotensive by the intravenous injection of hexa methonium showed that coronary blood flow increased slightly and that coronary vascular resistance decreased during the period of reduced blood pressure (92) A re duction of coronary flow would of course be profoundly significant from the clinical viewpoint and some insight into the matter has been gained from electrocardiographic tracings made during controlled hypotension (72 195 467) Intravenous hexamethonium and pentamethonium are capable of producing changes in the EKG character ized by a vacillating pulse rate extrasystoles, alteration in the site of the pacemaker and other arrhythmias and de

pression of the S T segment and T wave, suggestive of coronary insufficiency (127, 179) Similar changes occur during the conduct of controlled hypotension including depression of the S T segment and the T wave, disappear ance of the P wave and shortening of the P R interval (467) but these changes have been dismissed by the pro ponents of induced hypotension as not indicating myo-cardial ischemia (230) this is perhaps an unjustifiable assumption

The peripheral blood flow as measured in the digits of the hands and feet is increased under high spinal anal gesia despite the hypotension and decreased cardiac out put *(296 297, 409) Ganglionic blockade with methonium* compounds also effected an increase in the mean blood flow of the foot from an average control level of 1 0 cc /100 cc of foot volume to an average level of 9 8 cc /100 *cc of foot volume (427) This increase in peripheral blood* flow following the administration of hexamethonium and pentamethonium to the unanesthetized supine human being (14 71 145) however was not demonstrated in the patient under anesthesia (445)

Splanchnic blood flow following the administration of hexamethonium to the unanesthetized recumbent human subject fell in proportion to the fall in arterial blood pressure but no change was found in splanchnic vascular resistance (388) This is rather surprising in view of the fact that splanchnic vasodilatation has long been thought to play an important role in the production of the hypo-tensive state This data on splanchnic blood flow has been confirmed by studies during both low and high spinal analgesia in human beings, no significant changes in splanchnic resistance or oxygen consumption being found *(338)*

The circulation time is greatly prolonged following both spinal analgesia and ganglionic blockade produced

by ganglionic blocking agents (162), sometimes to twice the normal rate (145) and it is obvious that this slowing of the circulation may predispose to thrombosis and emboli particularly if the vessels are sclerotic

Effects on the Brain Since the brain, of all the tissues of the body is the least tolerant of anoxia, there has been considerable speculation over the effects of controlled hypotension upon that organ Two avenues of investigation have been pursued in this regard the nitrous oxide technique developed by Kety and Schmidt has been employed to measure cerebral blood flow (249) and cerebral function has been measured by both psycho-physical (345) and purely physical (65 425) tests

Studies of cerebral hemodynamics during induced hypotension in the unanesthetized subject have yielded conflicting results and cannot in any event be interpolated directly into the situation that pertains during controlled hypotension inasmuch as general anesthesia becomes a factor that cannot be ignored in the equation These investigations have been of great interest however for they bring out several facts of importance

In the first place it appears that in the supine position cerebral oxygen consumption is maintained near normal whether the induced hypotension is accompanied by a significant decrease in mean cerebral blood flow (331 332 337) or not (92 103) and that the compensatory mechanism responsible for this maintenance of near normal cerebral metabolism includes both a decrease in cerebral vascular resistance (92 103) and a more complete extraction of oxygen from the blood flowing through the brain as measured by an increased arteriovenous oxygen difference

A second important fact that has been revealed is that when a severe head up tilt of 30 to 40 degrees is superimposed upon hexamethonium induced hypotension (464)

in the unanesthetized subject these compensatory mechanisms no longer suffice to maintain cerebral metabolism and a critical level of cerebral blood flow is reached (between 23 9 and 45 8 cc per minute per 100 Gm Brain tissue with an average value of 35 0 cc per minute per 100 Gm brain tissue) at which the signs and symptoms (i e perspiration, cold clammy skin yawning somnolence slurring speech nausea and occasionally, convulsions) of cerebral ischemia become manifest (138) Similarly when hypotension is induced acutely by differential spinal block, there follows a significant diminution of the mean cerebral blood flow (250) Finally and perhaps very obviously, this critical level of systemic blood pressure at which cerebral ischemia occurs is of course much higher in the hypertensive subject (100 to 110 mm Hg mean femoral arterial pressure) (138)

Investigation of cerebral blood flow under the actual conditions of controlled hypotension during operation has been attempted by measuring the cerebral arteriovenous oxygen difference and then calculating the estimated cerebral blood flow (421) These studies were all made with the patient kept horizontal or nearly so and for this reason the results unfortunately shed no light upon cerebral hemodynamics when Trendelenburg or the reverse Trendelenburg positions are employed during controlled hypotension Hypotension was produced by the use of hexamethonium and the application of pneumatic suction to the patients legs (230 420) Under these conditions the arteriovenous oxygen difference was found to be 4 8 vol % (less than normal) and the estimated cerebral blood flow was 46 9 cc blood per minute per 100 Gm brain tissue Since this figure is roughly the equivalent of that found in a healthy adult breathing oxygen it was concluded that cerebral blood flow was certainly adequate to meet the metabolic demands of the brain in the presence

of the decreased cerebral oxygen demand occurring during general anesthesia It was also concluded that since the arterial blood pressures of these subjects ranged from 40 to 65 mm Hg during the observations that it may be assumed that controlled hypotension at such blood pressure levels does not produce deleterious effects upon the cerebral hemodynamics if the patient remains approximately horizontal

There is at least suggestive evidence however obtained both from psycho physical and from purely physical tests of cerebral function that cerebral metabolism is not maintained at a normal level during controlled hypotension in which the blood pressure is reduced to low levels and the patient is postured in the head up position

Nilsson has adapted the flicker fusion frequency test to the post-operative study of 15 patients who had been operated upon under hexamethonium induced hypotension Six of these 15 patients showed positive tests indicating cerebral injury presumably anoxic in origin and it is most interesting that although the cerebral injuries that were thus demonstrated were not serious five of the six positive tests occurred in patients who had been positioned with the head end of the table raised between 10 to 20 degrees during the operative (and hypotensive) period (345) This indicates that postural ischemia of the brain is a very real danger under these circumstances

Further evidence in this direction has been supplied by Bromage who employed the electroencephalogram as a measure of cerebral metabolism It has been recognized for some time that the electrical activity of the brain as recorded by the electroencephalogram becomes abnormal during cellular anoxia the normal alpha rhythm of 10 cycles per second is replaced by slow delta waves of less than four cycles per second and there is a reduction of the total electrical energy of the cortex In three conscious

volunteers who received pentamethonium intravenously and then were postured in a foot down tilt, the severe hypotension so produced was accompanied by coma con vulsions and profound disturbances of cortical rhythm the normal alpha rhythm being replaced by slow delta waves in irregular combination (65) It is obvious that conclusions drawn from this study must be limited inas much as the surgical patient undergoing controlled hypotension would be under general anesthesia (except during methods based upon conduction anesthesia not supple mented by basal narcosis) under these conditions, cerebral *metabolism is reduced almost 30% to 40% and differences* between the available oxygen supply and the cerebral oxy gen demand are less likely to occur than in the conscious volunteer

Effects on the Liver The anatomy and physiology of the hepatic blood supply are such that a higher critical level of hypotension exists for the liver than for most other tissues The blood supply to the liver is from two sources, the hepatic artery and the portal vein normally the for *mer supplies about 20% of the total hepatic inflow* at a relatively high oxygen tension (95% saturation) whereas the portal vein supplies the remaining 80% of the blood at a much lower (74%) degree of oxygen saturation When the circulation is slowed as during sympathetic paralysis and hypotension a point may be reached at which such a high degree of oxygen desaturation occurs in the intestinal capillaries that the oxygen tension of the blood in the por tal vein is nearly as low as that of the blood in the hepatic vein *(304) The liver will then depend entirely upon the* hepatic artery for its oxygen supply If the flow through the hepatic artery is reduced it may become inadequate for the total needs of the liver and local tissue anoxia will occur This in fact occurs during hypotension The liver

which has been subjected to anoxia becomes unable to form urea from ammonium salts or amino acids (281), loses the power to inactivate the vasodepressor material of Shorr (447, 448) and the deterioration of hepatic function is progressive until a point of irreversible change is reached (284)

This is the sequence of events that may occur under controlled hypotension The estimated hepatic blood flow was decreased 33% from the control value during high spinal analgesia (297) and the hepatic vein oxygen content decreased an average 30% (338) Local anoxia in the liver consequent to the reduced blood flow may then permit the action of V D M it has been observed during a series of laparotomies conducted under epidural blocks which were sufficiently extensive to cause the blood pressure to fall to 45 to 60 mm Hg that the livers were dark and cyanotic in appearance and turgid and rubbery in consistency these changes were reversed when the blood pressure was raised by the administration of methedrine or nor adrenaline (64)

Occult liver damage may result from this temporary hypoxia (5) Patients with normal pre-operative liver functions showed abnormal bromsulphalein retention for three to seven days after high spinal analgesia (297) and pathological changes have been shown to occur in the livers of experimental animals after hypotension induced with methonium compounds (432) Indeed hepatic damage may not necessarily be occult for one fatal case of liver necrosis has been attributed to the use of these techniques (445)

Effects on the Kidneys Any consideration of the effects of controlled hypotension on the kidneys must distinguish clearly between the suppression of urine formation during the period of hypotension and the depression of

renal function or the demonstration of morphological changes in the kidney following the restoration of normotension

The formation of urine is by a combination of glomerular filtration and tubular reabsorption When the blood pressure is lowered to 70 mm Hg or below in the normal human being the hydrostatic pressure in the glomeruli becomes insufficient to maintain filtration and urine formation may be expected to cease therefore when the arterial pressure reaches such a level during controlled hypotension Both empirical clinical experience and experimental evidence substantiate this hypothesis During spinal analgesia in the surgical patient renal function is reduced consistently during periods of hypotension (21 297) The same is true when the hypotension has been induced by ganglionic blockade the lowered systemic arterial pressure in both instances causing a reduction of glomerular filtration effective renal blood flow, and urine formation (253 306 308 321 323 475) The extent of these reductions is dependent upon the intensity of the hypotension a moderate fall in blood pressure will produce a decrease in the rate of glomerular filtration for a limited period of time but after an hour or more there will be a rise in the filtration rate despite the continued presence of hypotension (332 335 337) when the decrease in arterial pressure is profound however the inulin clearance rate is at a consistently low level in both man and the experimental animal (317 432)

The suppression of urine formation during the period of hypotension is therefore to be expected if the arterial pressure has been lowered to a significant degree but this fact cannot be construed to mean that renal damage has occurred or will occur In fact it has been argued that even at blood pressures lower than 70 mm Hg the continued viability of the renal epithelium is not endangered if effective ventilation with oxygen is maintained and the

arteriolar bed is dilated by sympathetic blockade On the other hand hexamethonium induced hypotension has been shown to cause proteinuria, and the presence of casts and red cells in the urine post-operatively (129) and these findings may (101) be indicative of renal damage (288) At any rate it appears certain that renal damage does in fact occur in view of the high incidence of renal complications and their occasional progress to fatal terminations following the use of the techniques of controlled hypotension (see Chapter X)

The Use of Vasopressor Agents There have been marked differences of opinion regarding the advisability of employing vasopressor drugs when it becomes desirable to restore the blood pressure toward normal levels during or at the end of 'controlled hypotension One school of thought has maintained that the blood pressure must be raised prior to closure of the wound in order to permit identification and ligation of all bleeding points since otherwise the danger of reactionary hemorrhage will be great when the pressure finally returns to normal and open vessels begin to bleed On the other hand there is a second school of thought which feels that to use a vasopressor drug at the end of operation is to defeat the purpose of the technique and that to employ one post operatively is to court disaster (440) The reasoning has been as follows during hypotension produced by arteriolar dilatation (i e, sympathetic blockade) clots form in the dilated vessels and when the vessels regain their tone following operation they contract down on these formed clots effectively sealing the vessels however if a vasopressor agent is administered or the blood pressure rises rapidly from any other cause these clots will be expelled and bleeding will ensue There is yet a third group of workers who do not employ vasopressor drugs ordinarily but will do so when the occasion warrants their use (Table XI)

Quite aside from the possibilities of reactionary hemor

rhage, however, the use of vasopressor drugs also must be considered in the light of recent knowledge of their actions during both anesthesia and hypotension Measurements of the contractile force of the heart have been made with

TABLE XI

THE USE OF VASOPRESSOR AGENTS IN CONTROLLED HYPOTENSION

	Anaesthetists in Great Britain and Ireland	*Anesthesiologists in U S A*	*Totals*
Vasopressors not Used	50	28	78
Vasopressors Used	38	63	101
Vasopressors Sometimes Used	90	45	135

strain gauge arches in intact dogs subjected to hexamethonium induced hypotension and indicate that conditions of hypotension associated with a weakened myocardium should dictate the use of such pressor amines as l arterenol methamphetamine or ephedrine, since these drugs will produce an increase in heart force in addition to the well known pressor responses (88) It is also important to remember before employing any vasopressor amines that some of these drugs may precipitate sinister cardiac arrhythmias when administered during anesthesia produced by chloroform cyclopropane, or trichlorethylene and even in the absence of those anesthetic agents vasopressor drugs may initiate dangerous arrhythmias if the tissues contain an increased concentration of carbon dioxide (101) Carbon dioxide retention to this extent occurs readily of course as a result of the respiratory depression following the induction of high spinal analgesia or the administration of methonium compounds in the techniques of controlled hypotension

X

Fatal and Non-Fatal Complications

THE PHYSIOLOGICAL derangements inherent in controlled hypotension have resulted in the occurrence of certain fatal and non fatal complications and it has been on the subject of these disasters that the great con troversy over these techniques has arisen As Armstrong Davison has put it, never since the days of the heated controversy about chloroform which divided the anaesthe tists of the United Kingdom has there been a matter which has so raised Emotion s end of the see saw with a corresponding depression of the end on which sits Reason It is particularly striking that the adherents of hypotension seem able to discount adverse effects while they presum ably are equally surprised that their opponents see lurk ing dangers in every shadow (101)

Complications The complication rate following the use of controlled hypotension is amazingly high The results of questionnaires sent to the members of the Association of Anaesthetists of Great Britain and Ireland revealed this complication rate to be one in every 32 cases the similar questionnaires sent to the Diplomates of the American Board of Anesthesiology reported a complication rate of one in 27 cases and since the total number of complica tions in the 27,930 cases contained in both series was 908 the over all complication rate was one in every 31 cases (Table XII)

The most common pertinent complication was *reaction*

ary hemorrhage, which occurred in 213 cases and thus constituted 27% of the total number of complications A very great deal of *nonsense has been written on the question*

TABLE XII

COMPLICATIONS IN 27 930 CASES OF CONTROLLED HYPOTENSION

Complication	*Great Britain and Ireland 21 125 Cases*	*U S A 6,805 Cases*	*Grand Total 27,930 Cases*
Anuria	54	8	62
Oliguria	30	24	54
Cerebral Thrombosis	20	9	29
Retinal Thrombosis	2	1	3
Coronary Thrombosis	15	3	18
Cardiac Arrest	7	15	22
Cardiovascular Collapse	11	25	36
Reactionary Hemorrhage	164	79	243
Persistent Hypotension	3	70	73
Delayed Awakening	193	3	196
Blurred Vision Post operatively	126	1	127
Others	28	17	45
Totals	653	255	908
Complication Rate	1 in 32	1 in 27	1 in 31

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of reactionary hemorrhage the tendency being to admit the theoretical possibility but to disclaim any knowledge of its actual occurrence It is worth pointing out that in at least eight of these 243 instances reactionary hemorrhage was not just trivial and annoying but sufficiently severe to cause death (see Table XIV) It is unfortunate that there is no data available to indicate whether it is the use or the avoidance of use of vasopressor agents at the end of surgery that is most likely to be correlated with the occurrence of reactionary hemorrhage (see Chapter IX)

The second most common complication has been a pro

longed and *delayed awakening time* after the operation and anesthesia have been terminated This phenomenon occurred on 196 occasions and was responsible for 22% of the total number of complications This slower recovery following controlled hypotension has been attributed in the past to either the synergistic effect which ganglionic blocking agents appear to have with general anesthetic drugs or the lowered metabolic rate induced by these drugs and responsible for their slower elimination from the body (371) Recent studies suggest that there may be a more important cause in the course of observations on electroencephalographic tracings during induced hypoten sion (65), it was noted that while normal subjects recov ered rapidly and completely when the blood pressure rose above 50 mm Hg an arteriosclerotic volunteer showed a delayed return to consciousness and normal cortical rhythm long after the blood pressure had been restored to a much higher level It is conceivable that the prolonged recovery time seen occasionally in patients who have been subjected to controlled hypotension may be due to cere bral anoxia rather than to the vasodilator drugs them selves

Blurred vision in the post operative period was the third most common complication and occurred a total of 127 times It was exhibited exclusively following the use of the methonium preparations and has been attributed to the long lasting action of these drugs upon the eye s power of accommodation While it was surely an inconvenience, it does not appear to have been a complication that carried with it any prolonged deleterious after effects (73 74)

Fourth in rank as concerns frequency of complications were disturbances involving the kidneys *anuria* occurring 62 times and *oliguria* on 54 occasions Considering the levels of blood pressure sought in the majority of these 27 930 cases of controlled hypotension (see Chapter IX)

it is rather surprising that there were not more complications involving renal function, but these figures do stress the fact that, of all the vital organs the kidneys are the most liable to damage or dysfunction during induced hypotension

Thrombotic phenomena within essential arterial supplies occurred a total of 50 times *cerebral thrombosis* in 29 patients, *retinal thrombosis* in three patients and *coronary thrombosis* in 18 patients There have also been word of mouth reports of *mesenteric thromboses,* but this complication was not reported on the questionnaires nor has its occurrence been remarked upon in the literature Thrombus formation is an evident danger when the circulation is slowed to the extent that pertains in controlled hypotension'

Cardiac arrest occurred in 22 cases and *cardiovascular* collapse in 36 cases and in roughly 25% of these cases the morbidity progressed to become a mortality (see Table XIV)

Certain other less frequent complications require comment When the blood is circulating through the peripheral vessels with what amounts to a reduced *vis a tergo* as is true during normovolemic hypotension the application of external pressure to the walls of those vessels may constitute a formidable impedance to the flow of blood within the vessel although such pressures would be tolerated well without causing obstruction to circulation under the ordinary circumstances of normotension What has been *termed retractor anemia is an example in point* during the conduct of neurosurgical procedures within the cranium under conditions of controlled hypotension, the retractors employed on the brain substance to provide adequate operative visualization may so restrict the cerebral circulation in the tissues on which they are exerting pressure that cerebral anoxia may result (18) This same situa

tion can occur in other tissues than the brain Pressure necrosis of the laryngeal mucosa has followed the use of an inflated endotracheal cuff in the presence of hypoten sion In another instance, disastrous aortic femoral throm bosis followed a difficult nephrectomy during which large packs placed in the depths of the wound under consider

TABLE XIII

CORRELATION OF BLOOD PRESSURE LEVELS WITH THE OCCURRENCE OF COMPLICATIONS IN 6,805 CASES OF "CONTROLLED HYPOTENSION

Complications	*Below 80 Mm Hg 3,071 Cases*	*80 Mm Hg or above 2,664 Cases*	*p*
Anuria	7	0	0 05>p>0 02 ? significant
Oliguria	17	5	
Cerebral Thrombosis	9	0	0 02>p>0 01 significant
Retinal Thrombosis	1	0	
Coronary Thrombosis	2	1	
Cardiac Arrest	14	1	0 01>p>0 001 highly significant
Cardiovascular Collapse	25	0	0 01>p>0 001 highly significant
Reactionary Hemorrhage	71	7	0 01>p>0 001 highly significant
Persistent Hypotension	53	7	0 01>p>0 001 highly significant

(Reprinted from Hampton L J and Little D M Jr *Arch Surg* 1953 with the kind permission of the publisher)

able pressure produced compression of the aorta while at the same time the blood pressure had been deliberately reduced to control bleeding Two cases of unilateral blind ness from retinal artery occlusion have occurred appar ently by this same mechanism during controlled hypo tension pressure on the eyeball by the anesthetic face mask being transmitted through the eye to prevent the flow of blood in the retinal artery (158)

Three major generalities may be made concerning these fatal and non fatal complications First it has become very clear that the extent or degree of hypotension is of para mount importance in respect to the occurrence of morbid

ities and mortalities Hypotension of the order of 80 mm Hg will be tolerated with far fewer complications than will hypotension below that level of blood pressure (Table XIII) Second it is evident that the duration of hypotension *is also of significance in respect to the causation of* complications 1¼ hours has been regarded as the upper limit in terms of the length of time that hypotension may be maintained although it is true that induced hypotension has been continued for far longer periods than this without the occurrence of obvious sequelae There is always the possibility, however, that irreversible shock may follow the use of these techniques and that a method conceived and begun as controlled hypotension may become quite literally uncontrolled hypotension (385) Third experimental studies have suggested that, while the extent and duration of hypotension are of obvious importance the abruptness of onset of hypotension may be a considerable factor in producing complications (425) The maintenance of the integrity of the cardiovascular system is a delicate and finely adjusted mechanism, and an abruptly induced, acute hypotension appears to be more dangerous than a hypotension of equal proportions that is brought on more slowly

Mortalities The deaths which have resulted from the use of the techniques of controlled hypotension have, in general followed the same etiological classifications as the complications and have represented most severe and fatal progressions of those complications In response to questionnaires on the subject British anesthetists reported 46 deaths in 21 125 cases or a mortality rate of one in 459 their American colleagues reported 50 deaths in 6 805 cases or a mortality rate of one in 136 cases and the total number of deaths reported in response to both questionnaires was 96 in 27 930 cases for an over all mortality rate

of one in 291 cases (Table XIV) The great disparity between the mortality rate in the British Isles and that pertaining on the American continent is of interest it may

TABLE XIV

MORTALITIES IN 27,930 CASES OF "CONTROLLED HYPOTENSION"

Cause of Death	*Great Britain and Ireland 21 125 Cases*	*U S A 6,805 Cases*	*Grand Total 27,930 Cases*
Renal Failure and Anuria	8	1	9
Cerebral Thrombosis or Anoxia	11	7	18
Coronary Thrombosis	7	1	8
Cardiac Arrest or Failure	6	3	9
Cardiovascular Collapse	1	4	5
Reactionary Hemorrhage	2	6	8
Following High Spinal	2	3	5
Over heparinization (Arteriotomy)	1		1
Arterial Air Embolism		1	1
Aortic Femoral Thrombosis		1	1
Pulmonary Infarcts and Edema		1	1
Persistent Hypotension		1	1
Neurosurgical Operative Trauma		14	14
Miscellaneous (Probably not Related)	8	7	15
Totals	46	50	96
Mortality Rate	1 in 459	1 in 136	1 in 291

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indicate that American anesthesiologists are far less skillful than their British counterparts or it may indicate that the patients subjected to controlled hypotension on this continent have been selected for indications that have been so urgent that the calculated risks involved are reflected in the mortality rate

Renal failure and anuria were the cause of death on nine occasions so that in almost 15% of the cases in which anuria was present as a complication a fatality ensued The

following is a typical case of a mortality resulting from anuria, and also serves to emphasize the dangerous results of hemorrhage during 'controlled hypotension

One death must be attributed to mismanagement of the technique A woman aged 65 years having a combined synchronous abdomino-perineal resection was given 50 mgm hexamethonium bromide Delay occurred in positioning her on the table and when the abdomen was opened although the blood pressure was at a satisfactory level of 80 mm Hg and there was no bleeding from the abdominal incision the veins of the pelvis were enormously dilated and extensive hemorrhage occurred Blood was replaced *four pints being given but return to normal* blood pressure was extremely slow Methedrine was given in repeated doses of 10 mgm and an adrenaline drip was started which kept her blood pressure at 100 mm Hg This was continued intermittently for three days She had complete anuria and died at the end of the third day (Reported on questionnaire sent to the members of the Association of Anaesthetists of Great Britain and Ireland)

Cerebral thrombosis and anoxia accounted for the largest number of deaths 18, and the following case history is illustrative of this sequelae which caused almost 20% of the reported deaths

A fit old man with a carcinoma of left pinna for excision with block dissection glands of neck Skin flap from occiput and graft from anterior abdominal wall

General condition B P 160/85 Electrocardiogram showed slight left ventricular preponderance

Anaesthetic Omnopon 1/6 grain scopolamine 1/300 grain Thiopentone 0 5 gm curare 15 mgm pethidine 50 mgm oxygen cocaine spray cuffed tube Nitrous oxide-oxygen Respiration assisted at first Feet down tilt 20 degrees Pentamethonium 50 mgm Fifty minute oper

ation during which left jugular vein tied Atropine 1/100 grain Neostigmine 2.5 mgm at end Electrocardiograms throughout hypotensive phase showed no change Consciousness did not return for 4½ hours post-op Patient then quite normal talking taking fluid by mouth moving all limbs B P 120/80 Next morning 24 hours post operatively found to be semi-conscious speech slurred left facial palsy left arm flaccid plantars extensor Died 3rd post-operative day

P M Very marked atheroma all parts of aorta Left internal carotid commencement completely occluded by clot and atheroma reduced lumen above clot to pin point Right internal carotid similar plaque of atheroma which had reduced lumen considerably—no clot Right middle cerebral artery recent thrombosis fairly near its origin Recent infarct on right parietal lobe Cerebral circulation was obviously impaired depending mainly on vertebral supply (84)

Thrombotic mechanisms were the major factor in causing death on the eight occasions in which they involved the *coronary arteries*, as in the next example

A fat woman with carcinoma of breast for radical mastectomy

General condition Good B P 172/98

Anaesthetic Omnopon 1/6 grain scopolamine 1/300 grain Thiopentone 0 5 gm Nitrous oxide-oxygen trichlorethylene (does not say whether intubated) Pethidine 50 mgm B P 130/84 Hexamethonium iodide 20 mgm Taken into theatre Positioned 10 degrees feet down Pethidine 25 mgm B P 98/70 Operation begun Hexamethonium iodide 10 mgm B P 80/58 Remained steady about this level for 40 minutes when it rose to 90/68 Pulse steady 100-108 Colour good peripheral circulation satisfactory Further pethidine 25 mgm during this time Just as removal of breast being completed (46 minutes after starting) peripheral circulation noted un

satisfactory and B P 50/40 Colour of face grey blue Lungs inflated with oxygen Table 10 degrees head down Methedrine 10 mgm i v Pulse imperceptible Fast plasma drip Further methedrine carbon dioxide 5 per cent oxygen 95 per cent inflation Operation ended at 64 minutes Condition much improved Colour and breathing satisfactory Pulse 120 B P 92/70 Just under one pint of plasma was given during operation Kept in theatre 10 minutes Then as her condition appeared satisfactory patient was transferred on a 10 degree head down trolley to bed which had been blocked Nasal oxygen started Suddenly died 20 minutes post-op

P M Both lungs grossly oedematous Air passages not obstructed Small area of infarction in left ventricle Anterior descending branch left coronary artery almost entirely blocked by atheroma (84)

Cardiac arrest or failure was the cause of nine of the 96 mortalities reported as in this instance

Thirty six year old white male undergoing subtotal thyroidectomy for toxic goiter Hexamethonium employed at the surgeon s request Some signs of toxicity still present in spite of iodine and propylthiouracil treatment Anesthesia induced with pentothal continued with endotracheal cyclopropane and ether C6 given with apparently satisfactory results Thirty minutes later blood pressure fell further and cardiac arrest occurred Cardiac massage performed and later defibrillation Cardiac action was reinstated but the patient failed to recover consciousness and died four hours later Cause of death not definitely determined but presumed to be cerebral and myocardial anoxia (Reported on questionnaire sent to Diplomates of the American Board of Anesthesiology)

Cardiovascular collapse was responsible for death in five patients, and may be exemplified in the following case record

A very old man for emergency excision of carcinoma of larynx

General condition Very poor risk Deep x ray therapy regarded as no avail B P 110/100 Some cyanosis due to obstruction Accessory muscles in use to some extent

Anaesthetic Atropine 1/75 grain Tracheotomy using 1 per cent procaine local Some degree of collapse occurred on inserting cuffed tube Says thiopentone and gallamine given but does not state definitely when Any way lungs inflated with oxygen Recovery in a minute or two Nitrous oxide-oxygen started Blood drip set up Blood pressure then 95/70 Considerable hemorrhage during tracheotomy so decided to use controlled hypotension Hexamethonium iodide 30 mgm Blood pressure fell to 50/40 Slope reduced from 25 degrees to 15 degrees feet down tilt Operation started and proceeded rapidly with negligible bleeding After 40 minutes on lifting larynx to cut through lower part prior to removal patient coughed and respirations became rapid Thiopentone 0 1 Gm and gallamine 8 mgm given but response inadequate Thiopentone 0 05 Gm and gallamine 4 mgm Response satisfactory Few minutes afterwards B P fell from 60/45 to 30/? and within few minutes patient died

P M Small amount of blood in bronchi, and it was thought that this entered during tracheotomy Heart and lungs otherwise in good condition No sign of coronary disease or thrombosis (84)

Reactionary hemorrhage, the most frequent complication also proved to be a major factor in the production of mortality eight deaths occurred for this reason as in the following instance

Middle aged healthy male—hemipelvectomy—ether anesthesia—hexamethonium 225 mgm —head-down position—B P 70 80 mm Hg systolic during greater part of operation—blood loss (measured) about 1000 cc.—re

placed during operation—B P returned to normal at end of operation with neosynephrine drip—patient apparently in good condition when he left O R

After return to ward B P and pulse disappeared A continuous drip of noradrenaline required to maintain circulation until time of death 48 hours later On the night of operation blood volume studies showed a marked deficit of red cells Hemorrhage was suspected and packed red cells were given since plasma volume was relatively good This was in addition to several transfusions given during the immediate post-operative hours Although no abnormal bleeding could be detected at time of blood volume studies on morning of first post operative day blood had distended the abdomen penis and scrotum In spite of blood replacement and noradrenaline drip, his condition steadily deteriorated and he died on the morning of the second post-operative day

Autopsy revealed massive hemorrhage into the peritoneal cavity and external genitalia as well as the operative site No large vessels could be discovered as the cause of bleeding It appeared to have been due to a generalized capillary ooze In addition there were pulmonary edema and acute passive congestion of the lungs central lobular ischemic necrosis of the liver hemorrhagic infarction of the spleen and kidney and hemoglobinuric nephrosis secondary to shock The question arose as to whether these changes were due to C6 or could in part be attributed to prolonged vasoconstriction (Reported on questionnaire sent to Diplomates of the American Board of Anesthesiology)

There were five patients who died *following the administration of high spinal anesthesia,* as in the following case history

A healthy man with a prolapsed lumbar disc

General condition Operation five years ago for disc Good result until seven weeks ago when twisting spine

caused severe recurrence B P 110/70 Apical systolic mur mur

Anaesthetic Morphine 1/4 grain scopolamine 1/100 grain Thiopentone 1 Gm No apnea Intubation easy Put into face-down jack knife position Maintenance with nitrous oxide-oxygen trichlorethylene Spinal with heavy nupercaine 1 8 ccm Head-down tilt increased Blood pressure fell to unreadable levels Respiration rate fell to 8/min Methedrine given i v Apnoea Inflation with oxy gen turned on back heart massage intra aortic saline, more methedrine Only momentary response

P M nothing significant (81)

Finally there were 14 deaths in which the *neurosurgical operative trauma* was considered the major cause of de mise or at least could not be excluded as a possible factor of major significance To quote one of the replies to the questionnaires

Two patients have died 48 hours after operation and one patient has died 72 hours after operation In these neurosurgical patients it has been impossible to determine whether death was due to pre existing disease the sequelae of operative trauma or the induced hypotension

This is perhaps an appropriate note upon which to end a discussion of complications and mortalities for there is reason to question the validity of ascribing to induced hypotension the entire burden of guilt in the causation of these complications and deaths herein described It is true that in many instances the techniques of controlled hypo tension would appear to be implicated but until there are comparable series of cases run with and without the use of these techniques it is unfair to attribute all deaths occurring in surgical patients in whom hypotension has been induced as being the direct result of that hypo tension

XI

Contraindications

INSIGHT into the contraindications to the employment of controlled hypotension follows most naturally upon knowledge of the physiological aberrations produced by these techniques and the morbidities and mortalities consequent to their use The major concern, not unreasonably, has been expressed over the state of the cardiovascular system particularly the presence of disease in the various branches of the vascular tree, and over the status of the blood volume and the oxygen carrying capacity of the blood within those vessels In the questionnaires sent to the members of the Association of Anaesthetists of Great Britain and Ireland and to the Diplomates of the American Board of Anesthesiology each physician was requested to designate his considered contraindications to the use of these techniques (Table XV)

The presence of *arteriosclerosis*, known *coronary disease* or previous *cerebrovascular disease* must be considered absolute contraindications to the employment of controlled hypotension since there is great danger that the flow of blood through vessels which are already partially occluded may cease altogether under conditions of hypotension The risk of coronary thrombosis or occlusion is very real during hypotension, even in the absence of known coronary insufficiency (203) and in spite of the hypothesis that vasodilatation and lowered peripheral resistance will reduce the work load of the heart (175) Furthermore since the circulation time is increased almost two fold during induced hypotension thrombus formation

is very likely and especially so in the presence of narrowed vessels The fact that cerebral blood flow, for example, may be maintained near normal in moderate degrees of hypotension by a decrease in cerebral vascular resistance does

TABLE XV

CONTRAINDICATIONS TO CONTROLLED HYPOTENSION

	Anaesthetists in Great Britain and Ireland	*Anesthesiologists in U S A*	*Totals*
Cardiovascular Disease			
In General	48	19	67
Coronary Disease	62	57	119
Arteriosclerosis	51	30	81
Cardiac Disease	46	45	91
Cerebrovascular Disease	32	22	54
Hypertension (Severe)	43	24	67
Hepatic Disease	8	14	22
Renal Disease	48	40	88
Extremes of Age	82	31	113
Disturbances of Blood Volume			
Anemia	18	18	36
Hemorrhage	10	7	17
Shock	40	12	52
Low Blood Volume	30	19	49
Polycythemia	3	4	7
Uncomplicated Elective Surgery	54	17	71
Others	58	59	117

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not necessarily mean that there is less likelihood of cerebral thrombosis for if cerebral vascular resistance is reduced by dilatation of the cerebral vessels which is the mechanism that must be assumed unless blood viscosity or intracranial tension are considered to vary the slowing of the linear flow rate and the prolongation of the local circulation time will enhance the possibility of the development of intravascular thrombosis (103)

Cardiac disease in general and particularly *cardiac* failure have been considered contraindications to the use of

these techniques and in the present state of knowledge this is undoubtedly the correct view It is worth noting in passing, however that the cautious use of ganglionic blocking agents in the therapy of cardiac failure is now under trial, based on the same rationale as the use of phlebotomy or spinal block in the past, and hypotensive techniques may well play an active part in the anesthesia for certain cardiac patients in the future

Severe and malignant *hypertension* must be considered an absolute contraindication to controlled hypotension, but only when excessively severe In all other forms, hypertension is only a relative contraindication, if the exaggerated effects of hypotension upon cerebral blood flow renal blood flow, and other parts of the cardiovascular mechanism in the hypertensive subject are kept in mind

The presence of *hepatic disease* must certainly constitute an absolute contraindication as must the presence of *renal disease* Liver failure is liable to follow extreme hypotension due to the peculiarities of the hepatic blood supply and a case of acute hepatic necrosis has already been reported following the use of methonium induced hypotension (445) Tests of renal function during and after controlled hypotension demonstrate quite clearly the adverse effects that these techniques may have on the kidneys when the latter are in a diseased state There is a further consideration in connection with kidney function which was mentioned previously and may be extremely important both the methonium compounds and arfonad depend at least in part upon the kidneys for their excretion In the presence of profound hypotension glomerular filtration is reduced to such an extent that urinary excretion of these drugs does not occur a vicious cycle is then set up in which failure of the kidneys to excrete these ganglionic blocking agents produces a continuance of their hypotensive effects As would be expected this is particu

larly prone to occur when the kidneys themselves are diseased

A further absolute contraindication to the use of the techniques of controlled hypotension' is a disturbance of blood volume and oxygen carrying capacity of the blood such as *anemia, hemorrhage,* and *low blood volume* *Shock* and *hypotension* are usually part of the clinical picture of such disturbances of blood volume and are, of course contraindications in themselves In Addison s Disease, hypotension exists already, and although the blood volume may be relatively normal further reduction of the blood pressure must be considered unsafe Extreme in*crease in blood volume is also a contraindication because* of the markedly slowed circulation the tendency toward thrombotic episodes in patients with *polycythemia vera* must not be aggravated through further slowing of the circulation by the induction of hypotension

There is another absolute contraindication of importance If the operating room team, the personnel responsible for post operative care or the *facilities for either operative or post operative care* are in any way deficient controlled hypotension should not be employed These are not techniques for the occasional operator or anesthetist they are not techniques for inexperienced or slow surgeons and they are not techniques which can be employed safely when routine post operative care is the only such care available

The *extremes of age* have often been considered as contraindications but it would appear that these are only relative contraindications Patients under sixteen years of age are often resistant to ganglionic blocking drugs particularly the methonium compounds and it is therefore occasionally difficult to induce a satisfactory hypotension in such patients This would appear to constitute a failure of the technique rather than a contraindication to its

use, excepting that this failure can on occasion be danger ous of itself for if the ganglionic blockade produces partial vasodilatation, without a marked fall in blood pressure, operative bleeding may be actually increased (120) The use of these techniques in patients over 60 years of age has also been considered a contraindication, because of the possibility of unsuspected and latent cardiovascular disease (203) However the absolute chronological age of the patient is far less important than the physiological age of his or her arterial tree

Diabetes Mellitus is also a relative contraindication, at least to the use of the methonium compounds for there is a tendency for the blood sugar to fall during the adminis tration of these drugs The hypoglycemia which occurs as a result may become very profound without being recog nized since the usual symptomatology of sweating, palpi tation, restlessness and anxiety, are due to sympathetic and adrenal discharge and hence do not occur in the pres ence of ganglionic blockade The accentuation of the effects of the administration of insulin in the diabetic patient by the methonium compounds together with the masking of these effects by general anesthesia, can result in a very dangerous situation (12 176)

Without question however, the most absolute of all contraindications to the use of the techniques of 'con trolled hypotension must be the *absence of a rational and urgent indication* There can be no justification for the use of induced hypotension merely for convenience during uncomplicated and elective surgery Controlled hypo tension is not a luxury during surgery it is an occasional necessity and must be employed only under conditions of the most compelling need There are grave dangers associated with its use but there are also on occasion, great advantages to be attained from that use The method must therefore be considered contraindicated in those

situations in which the advantages do not outweigh the risks involved

These contraindications just listed are of immense importance and failure to respect them can lead to disaster They do not represent merely a list of pathological entities which might conceivably be of theoretical danger they are conditions which bitter empirical experience has taught are incompatible with the successful conduct of 'controlled hypotension

XII

Indications

THE INDICATIONS for which controlled hypotension is employed are the crux of the problem concerning these techniques On what basis does one seek to induce hypotension and when does one fight to maintain a normal arterial pressure? There is no glib answer to this riddle unless it were to be Sir John Gillies statement to the effect that *there is only one true indication for induced hypotension* that situation in which its advantages will be of certain benefit to the patient and likely to outweigh the assumed risks

In any discussion of the indications for the use of controlled hypotension therefore it is imperative to make a clear distinction between the specific operative procedures for which these techniques have been employed in the past and the clinical situations for which their use is justifiably indicated Controlled hypotension has been advocated for a large variety of operative procedures including such unlikely choices as tonsillectomy dental extractions and caesarean sections Most commonly however it has been employed during extensive surgical interventions in which there could be expected to be a large amount of bleeding sudden or profuse hemorrhage or greatly increased tension within vessels or organs

The categorical listing of these procedures is a long one (Table XVI) *neurosurgical procedures* (18 26 27 80 187 188 189 207 228 318 322 375 376 378 381 394 451 474 491 492 501 515) particularly the removal of highly vascular tumors (4) the ligation of various types of

intracranial aneurysms (377, 395, 466, 508), and the removal of meningiomas (151), *head and neck surgery*, such as the Lempert fenestration operation (135, 168 200 224, 347, 494) opthalmic surgery (399) in the presence of glau

TABLE XVI

TYPES OF OPERATIVE PROCEDURES FOR WHICH CONTROLLED HYPOTENSION HAS BEEN EMPLOYED

- Neurosurgery
  - Vascular Brain Tumor Congenital Aneurysm Meningioma
- Head and Neck Surgery
  - Lempert Fenestration Operation Ophthalmic Surgery Radical Neck Dissection Thyroidectomy Laryngectomy
- Surgery of Chest Wall
  - Radical Mastectomy Thoracoplasty
- Intra thoracic Surgery
  - Pneumonectomy Lobectomy Decortication Esophago gastrectomy
- Cardiovascular Surgery
  - Coarctation of Aorta Patent Ductus Arteriosus Aortic Aneurysm
- Abdominal Surgery
  - Radical Abdominal Operation Abdomino perineal Resection Gastrectomy Porta caval Shunt
- Pelvic Surgery
  - Pelvic Evisceration Radical Hysterectomy Pelvic Node Dissection
- Orthopedic Surgery
  - Spinal Fusion Laminectomy Open Hip Operation Bone Graft
- Genito urinary Surgery
  - Prostatectomy Transurethral Resection Nephrectomy Adrenalectomy Vesico vaginal Fistula Vaginal Plastic Operation
- Plastic Surgery
  - Skin Graft Skin Flap

coma (73 211), a number of otorhinolaryngological procedures (155 168, 282, 355 506) thyroidectomy (231 398) radical neck dissection (223 231) and laryngectomy *surgery of the chest wall*, specifically radical mastectomy (231) and thoracoplasty (398) *intra thoracic surgery* (105 291 422) such as pneumonectomy (79 96) lobectomy decortication and esophago-gastrectomy (67) *cardiovascular surgery* (110 210) particularly that involving large vessels (166) such as coarctation of the aorta patent ductus arteriosus and aortic aneurysms *abdominal surgery* (58, 59 60 111) including radical abdominal operations,

gastrectomy abdomino perineal resection thoraco lumbar sympathectomy (175 240) and porta caval shunt *pelvic surgery* (58 59 60 270) particularly pelvic evisceration radical hysterectomy and pelvic node dissection *orthopedic surgery* (462) such as spinal fusion, laminectomy (382) open hip operation (242) and bone grafts *urological surgery* (497) including adrenalectomy nephrectomy prostatectomy (50 85 86 87 325 393) vesico vaginal fistula and vaginal plastic operation and *plastic surgery* (43 373) particularly skin grafts and skin flaps It must be emphasized that long as this list is it is by no means complete for there is scarcely an operative procedure to which the techniques of controlled hypotension have not been applied

Yet there are no specific operative procedures for which the use of controlled hypotension is indicated and an enumeration of the surgical interventions for which it has been employed must never be confused with the indications for its use There are as previously stated a number of well defined clinical situations during operations in which the use of these techniques may become mandatory and without which the operations would be totally unfeasible *immensely more dangerous* or *more likely to result* in unsuccessful outcomes these are the indications for the use of controlled hypotension (Table XVII)

Surgical Indications *Foremost among the indications* for the use of controlled hypotension must be the *control* of gross hemorrhage during operative procedures for such *lesions as intracranial aneurysms vascular brain tumors* and definitive interventions for the excision of other highly vascular lesions which are capable of sudden and profuse hemorrhage An indication of less dramatic but equally important significance has been the *control of extensive capillary ooze* during operations of considerable magnitude such as abdominal or pelvic eviscerations or

radical node dissection The amount of blood lost need not necessarily be great to require the use of induced hypotension the Lempert fenestration operation for example, entails very little actual blood loss yet the techniques of

TABLE XVII

INDICATIONS FOR CONTROLLED HYPOTENSION

Surgical	
Control of gross hemorrhage—i e	intracranial aneurysm
Control of extensive ooze—i e	abdominal evisceration
Bloodless field for visibility—i e	fenestration
Reduction of organ tension—i.e	craniotomy
Reduction of intravascular tension—i e	cardiac and great vessel surgery
Control of hypertensive crises—i e	pheochromocytoma
Avoidance of transfusions—i e	compatible blood unavailable history transfusion reactions
Anesthetic	
Obtundation of noxious stimuli by ganglionic blockade	
Artificial hibernation	
Medical	
Treatment of pulmonary edema in hypertensive crises	
Therapy in pulmonary embolism	
Pain relief in herpes zoster	
Relief of venous congestion in cardiac failure	
Treatment of severe hemorrhages	

controlled hypotension may be indicated, for the purpose of increasing *visibility in the operative site,* by the presence of even a single drop of blood which can obscure the entire operative field during the delicate maneuver of shaping the fenestra and thus negate a successful surgical result

The indications for the usage of controlled hypotension must also include those situations in which although bleeding may be expected to be minimal, the tensions within the vessels or organs themselves will be of such magnitude as to endanger the life of the patient or to render improbable a satisfactory completion of the surgical procedure During the course of craniotomies in patients with hugely swollen and edematous brains these

techniques can be employed to *reduce organ tension* and so to facilitate surgical exposure, which might otherwise be totally unsatisfactory, and the same may be true of operations upon the glaucomatous patient, in whom the reduction of arterial pressure leads to a secondary reduction of pressure within the eyeball and permits the performance of operations that would under other circumstances be highly dangerous A similar situation pertains during certain instances of cardiac and great vessel surgery, in which, by the *reduction of intravascular tension*, it may become possible to place clamps upon tense and bulging vessels, which would tear and precipitate massive hemorrhage were the tensions within the lumens not reduced by controlled hypotension The reduction of vascular tension may be indicated also in certain rarer instances of surgery during which *hypertensive crises* may threaten to explode quite literally into hemorrhagic accidents a situation encountered in such surgery as the removal of pheochromocytoma (83)

There are certain less frequent indications for the use of controlled hypotension during anesthesia and surgery which should be cited One such indication is the *avoidance of transfusion* emergency surgery of an acute nature may be necessary in the absence of compatible whole blood for transfusion, and the use of these techniques can prevent blood loss to a degree that transfusion may be avoided altogether A similar indication may arise in the rare patient with a history of multiple transfusion reactions who must undergo extensive surgery the use of controlled hypotension in such a patient may circumvent the danger of a major transfusion incompatibility by decreasing blood loss to such an extent that transfusion is not essential (327) These would be most infrequent indications under modern operating conditions

Anesthetic Indications One interesting outgrowth of

the use of controlled hypotension in anesthesia and surgery has been *the use of ganglionic blockade to prevent the transmission of noxious impulses* This is not, of course a true indication for induced hypotension itself, but it has been suggested that the future may prove that this usage of ganglionic blockade is the most important and enduring contribution that the techniques of "controlled hypotension have made to medicine The basis of this use of ganglionic blockade to prevent the transmission of noxious impulses harks back to the theory of Anociassociation pronounced by George Crile, senior some 40 years ago Crile, reasoning along physiological lines, argued that not only must the brain be protected against destructive psychic strain by the use of general anesthesia, but that local anesthesia must be employed also to exclude the noxious impulses arising from the site of surgical intervention (90) It is now apparent that many of these noxious impulses are conveyed by the autonomic nervous system and therefore are susceptible to ganglionic blockade (57 82 389) The clinical impression has been gained that patients subjected to controlled hypotension develop surgical shock less frequently than do other surgical patients (510), and that obtundation of noxious impulses by ganglionic blockade is feasible (39 436)

The French have made specific utilization of these ideas in their techniques of artificial hibernation in which induced hypotension is one of the several essential factors in a combination that includes hypothermia central nervous system depression muscle relaxation and that evasive delight déconnexion (484)

Medical Indications Finally and similarly an increasing number of medical therapies have been based upon the use of the ganglionic blocking agents which have achieved prominence through their employment in the techniques of controlled hypotension the treatment of

pulmonary edema in hypertensive crises (95, 415 416 417 418, 419) the therapy of *pain and neurogenic shock in pulmonary embolism* (91, 429) *pain relief in herpes zoster* (346), the *potential relief of venous congestion in cardiac failure,* (505) and the *treatment of severe hemorrhages* (109, 199, 280) and cerebrovascular bleeding (430) a revolutionary but apparently effective therapy The further extension of the use of ganglionic blockade in the therapy of a number of other pathological processes seems assured

XIII

Requirements

THE CONDUCT of a surgical intervention performed under the techniques of controlled hypotension demands meticulous attention to detail and rigid adherence to a set of fundamental tenets Any lapse in the fulfillment of the requirements is a sure invitation to disaster, for these are techniques which are quite capable of either maiming or killing the patient This is not to say that they should be forbidden techniques for most assuredly the results of their use can often be useful sometimes beneficial, and on occasions truly life saving but these are services that are achieved at a price and at times the price may be inordinately high There is a growing tendency throughout medicine but perhaps particularly in anesthesia and surgery to equate what is new with what is good and to confuse the means with the end—especially where the means are striking and dramatic It therefore devolves upon those who induce hypotension deliberately in the surgical patient to adopt rigid criteria for the execution of the details of controlled hypotension (Table XVIII) for the usefulness of these techniques is entirely dependent upon their successful performance

The most unyielding of these requirements without which all the others become meaningless is the absolute necessity for selecting patients to be subjected to these techniques on the basis of the most *urgent and rational indications* Such indications must be based upon the probable failure either of the patient to survive the operation or of the surgery to be completed successfully without the

use of controlled hypotension' The use of these techniques in the absence of a rigidly-defined indication is at best poor judgment and is at worst closely akin to malpractice

As a corollary to the requirement that there must be the most scrupulous selection of cases on the basis of indi

TABLE XVIII

THE REQUIREMENTS OF CONTROLLED HYPOTENSION

1	A rational and urgent indication
2	Respect for existing contraindications
3	Restriction of extent and duration of hypotension
4	Normal pre-operative blood volume
5	Drop by drop replacement of blood and fluid loss
6	Adequate oxygenation
7	Due consideration to posture
8	Completely competent anesthesiologist and surgical team
9	Detailed and meticulous post operative care

cations that are so urgent that operation could not be performed successfully in the absence of the employment of these techniques it is mandatory that any *existing contraindications be respected* in the most assiduous manner These contraindications must be considered to include disease of various branches of the vascular tree hepatic and renal disease, and blood volume disturbances of a number of different types (see Chapter XI) A failure to recognize the existence of these pathological entities prior to the induction of hypotension in the surgical patient has been responsible, in the past, for some of the tragic morbidities and mortalities which have followed upon the use of controlled hypotension The occasional clinical situation does arise in which the need and indication for controlled hypotension is so overwhelming that the physician s judgment dictates that an existing contraindication must be ignored such situations are indeed rare however

When a pregnant indication for the use of controlled hypotension does exist and the decision is made to em

ploy the technique, it is essential that the *blood pressure be lowered slowly to the maximal level compatible with the control of bleeding, and that it be maintained at this lowered level the shortest time consistent with the adequate accomplishment of the surgical intervention* It has become very clear that the morbidities and mortalities associated with the use of induced hypotension have been directly related to both the extent and the duration of the reduction of the blood pressure from the pre operative normal From a purely realistic and practical standpoint, it is almost always possible to restrict the period of hypotension to that part of the operative procedure for which its benefits are most necessary, and advantage should be taken of this fact Furthermore since the level of the blood pressure which must obtain in order to provide a relatively bloodless field varies tremendously between individual patients the degree of the hypotension should never be greater than that required in the patient under consideration

These techniques are based upon the production of either a normovolemic or a hypovolemic hypotension and in both instances a point is reached at which the wide spread transgressions of the physiological status quo of the cardiovascular system may progress to irreversible shock This point may be reached with deceiving rapidity when the blood volume is abnormally low at the time of the induction of hypotension or if it is lowered by hemorrhage during the course of the conduct of controlled hypotension For this reason it is a requirement that there be an absolutely *normal pre operative total blood volume* and red cell mass Furthermore it is necessary to recognize that a low pre operative blood volume often cannot be distinguished on purely clinical grounds or even by the usual laboratory investigations so that the selection of patients should be made on the basis of blood volume determinations This is particularly true of the older

cachectic patient with extensive malignant involvement, who represents a state which has been termed 'chronic shock

By the same token hemorrhage or extensive bleeding which occurs during the course of controlled hypotension also will lead rapidly to the point of irreversible shock, for it has become apparent that patients in whom hypotension has been induced tolerate blood loss poorly A further requirement therefore must be the *drop by drop replacement of all blood and fluid that is lost* during operation It should be unnecessary to add that an indwelling cannula into some part of the vascular tree is quite indispensible

When hypotension has been induced, the oxygen-carrying capacity of the blood must be utilized to the fullest extent if tissue oxygenation and cellular respiration are to be maintained near normal The accomplishment of this task of *adequate oxygenation* requires a completely patent airway at all times high flows of oxygen and adequate (preferably spontaneous) ventilation of the lungs

Due consideration to the posture of the patient is extremely important in controlled hypotension This matter is of concern not only to promote venous drainage from the wound but also in order to effect the necessary level of hypotension in many instances At the same time it must be remembered that the position of the patient is often the key to morbidity or mortality in these techniques Certain postures such as steep Fowler s position, have an undesirable effect upon the blood flow to vital organs particularly the brain Furthermore shifts of posture in the presence of a dilated vascular bed carry their own inherent risks since a further and more severe hypotension can be so induced with a consequent reduction of venous return to a point incompatible with continued circulatory function

These heroic maneuvers of controlled hypotension

demand the utmost from those employing the techniques, which means that there must be a *completely competent surgical team* Not only must the anesthesiologist be highly trained, skilled, and thoroughly conversant with the technique employed, but also the operating surgeon and his assistants must be dextrous, accomplished, and possessed of a complete understanding of what is being undertaken In perhaps no field of surgical endeavour is there greater need for the utmost in cooperation between all members of the operating team

Since the dangers to the patient during the immediate post-operative period are at least as great as during the operation and the period of hypotension itself, a final requirement is for *detailed and meticulous post operative care* Posture, airway, oxygenation, determinations of hematocrit and total blood volume, and constant observation, are all of concern in the post operative period, for the end of operation does not necessarily signify the end of ganglionic blockade nor the attainment of a normotensive state

In a recent survey studying the effects of anesthesia and surgery in 599 548 surgical patients the anesthetic death rate was found to be one in 1560 patients (36) in 27 930 cases of controlled hypotension, the over all mortality rate has been found to be one in 291 patients This is indeed a staggering figure Let there be no doubt that these are gravely dangerous techniques, possessing those inherent capacities for tragedy which always accompany marked deviations from the normal physiological status quo It would be at least convenient merely to dismiss controlled hypotension as a menace to humanity unfortunately the situation is scarcely that simple For these are techniques which although potentially lethal are capable of immense benefit for the patient when employed for good and sufficient reason by the knowing, the wary, and the skilled

XIV

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